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THE AMERICAN FISHERIES SOCIETY

Organized 1870 Incorporated 1910

The Society was organized to promote the cause of fish culture; to gather and diffuse information of a scientific character; and to unite and encourage those interested in fish culture and fishery problems.

Officers for 1944-1945

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Librarian—Kenneth E. Cobb, Windsor Locks, Conn

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Fish Culture—James R. Simon, Cheyenne, Wyo.
Aquatic Biology and Physics—R. W. Eschmeyer, Norris, Tenn.
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Executive Committee

The Executive Committee consists of the president, vice-presidents, secretary-treasurer, vice-presidents of divisions, and James Brown, the immediate past president.

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C. McC. Mottley	Ithaca, N. Y.

[1]Elected by the membership.
[2]Each member serves for 5 years; one new member is appointed each year by the incoming President.

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SETH GORDON	Harrisburg, Pa.
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S. B. LOCKE	Boston, Mass.
EMMELINE MOORE	Albany, N. Y.
JAMES A. RODD	Ottawa, Ont.
M. W. SMITH	St. Andrews, N. B.

[a]Appointed by the President-elect, in accordance with a motion adopted by the membership.

PRESIDENTS' TERMS OF SERVICE AND PLACES OF MEETING

The first meeting of the Society occurred December 20, 1870. The organization then effected continued until February, 1872, when the second meeting was held. Since that time there has been a meeting each year, as shown below. The respective presidents were elected at the meeting, at the place, and for a period shown opposite their names, but they presided at the subsequent meeting.

1.	William Clift	1870-1872	New York, N. Y.
2.	William Clift	1872-1873	Albany, N. Y.
3.	William Clift	1873-1874	New York, N. Y.
4.	Robert B. Roosevelt	1874-1875	New York, N. Y.
5.	Robert B. Roosevelt	1875-1876	New York, N. Y.
6.	Robert B. Roosevelt	1876-1877[1]	New York, N. Y.
7.	Robert B. Roosevelt	1877-1878	New York, N. Y.
8.	Robert B. Roosevelt	1878-1879	New York, N. Y.
9.	Robert B. Roosevelt	1879-1880	New York, N. Y.
10.	Robert B. Roosevelt	1880-1881	New York, N. Y.
11.	Robert B. Roosevelt	1881-1882	New York, N. Y.
12.	George Shepard Page	1882-1883	New York, N. Y.
13.	James Benkard	1883-1884	New York, N. Y.
14.	Theodore Lyman	1884-1885	Washington, D. C.
15.	Marshall McDonald	1885-1886	Washington, D. C.
16.	W. M. Hudson	1886-1887	Chicago, Ill.
17.	William L. May	1887-1888	Washington, D. C.
18.	John Bissell	1888-1889	Detroit, Mich.
19.	Eugene G. Blackford	1889-1890	Philadelphia, Pa.
20.	Eugene G. Blackford	1890-1891	Put-in-Bay, Ohio
21.	James A. Henshall	1891-1892	Washington, D. C.
22.	Herschel Whitaker	1892-1893	New York, N. Y.
23.	Henry C. Ford	1893-1894	Chicago, Ill.
24.	William L. May	1894-1895	Philadelphia, Pa.
25.	L. D. Huntington	1895-1896	New York, N. Y.
26.	Herschel Whitaker	1896-1897	New York, N. Y.
27.	William L. May	1897-1898	Detroit, Mich.
28.	George F. Peabody	1898-1899	Omaha, Nebr.
29.	John W. Titcomb	1899-1900	Niagara Falls, N. Y.
30.	F. B. Dickerson	1900-1901	Woods Hole, Mass.
31.	E. E. Bryant	1901-1902	Milwaukee, Wis.
32.	George M. Bowers	1902-1903	Put-in-Bay, Ohio
33.	Frank N. Clark	1903-1904	Woods Hole, Mass.
34.	Henry T. Root	1904-1905	Atlantic City, N. J.
35.	C. D. Joslyn	1905-1906	White Sulphur Springs, W. Va

[1] A special meeting was held at the Centennial Grounds, Philadelphia, Pa., October 6 and 7, 1876.

36.	E. A. Birge	1906-1907	Grand Rapids, Mich.
37.	Hugh M. Smith	1907-1908	Erie, Pa.
38.	Tarleton H. Bean	1908-1909	Washington, D. C.
39.	Seymour Bower	1909-1910	Toledo, Ohio
40.	William E. Meehan	1910-1911	New York, N. Y.
41.	S. F. Fullerton	1911-1912	St. Louis, Mo.
42.	Charles H. Townsend	1912-1913	Denver, Colo.
43.	Henry B. Ward	1913-1914	Boston, Mass.
44.	Daniel B. Fearing	1914-1915	Washington, D. C.
45.	Jacob Reighard	1915-1916	San Francisco, Calif.
46.	George W. Field	1916-1917	New Orleans, La.
47.	Henry O'Malley	1917-1918	St. Paul, Minn.
48.	M. L. Alexander	1918-1919	New York, N. Y.
49.	Carlos Avery	1919-1920	Louisville, Ky.
50.	Nathan R. Buller	1920-1921	Ottawa, Canada
51.	William E. Barber	1921-1922	Allentown, Pa.
52.	Glen C. Leach	1922-1923	Madison, Wis.
53.	George C. Embody	1923-1924	St. Louis, Mo.
54.	Eben W. Cobb	1924-1925	Quebec, Canada
55.	Charles O. Hayford	1925-1926	Denver, Colo.
56.	John W. Titcomb	1926-1927	Mobile, Ala.
57.	Emmeline Moore	1927-1928	Hartford, Conn.
58.	C. F. Culler	1928-1929	Seattle, Wash.
59.	David L. Belding	1929-1930	Minneapolis, Minn.
60.	E. Lee LeCompte	1930-1931	Toronto, Canada
61.	James A. Rodd	1931-1932	Hot Springs, Ark.
62.	H. S. Davis	1932-1933	Baltimore, Md.
63.	Fred A. Westerman	1933-1934	Columbus, Ohio
64.	E. L. Wickliff	1934-1935	Montreal, Canada
65.	Frank T. Bell	1935-1936	Tulsa, Okla.
66.	A. G. Huntsman	1936-1937	Grand Rapids, Mich.
67.	I. T. Quinn	1937-1938	Mexico City, Mexico
68.	Fred J. Foster	1938-1939	Asheville, N. C.
69.	T. H. Langlois	1939-1940	San Francisco, Calif.
70.	James Brown	1940-1941	Toronto, Canada
71.	John Van Oosten	1941-1942	St. Louis, Mo.
72.	John Van Oosten	1942-1943	(No meeting.)[2]
73.	John Van Oosten	1943-1944	(No meeting.)[3]
73.	John Van Oosten	1943-1944	(No meeting.)[3]

[2]The annual meeting scheduled to be held in New Orleans, La., was cancelled because of the war emergency.
[3]No annual meeting scheduled because of the war.

In Memoriam

Clarence M. Baker, Madison, Wis.

S. Morris Pell, Huron Mountain, Mich.

E. L. Sibley, Bennington, Vt.

W. T. Thompson, Bozeman, Mont.

Charles H. Townsend, Coral Gables, Florida

Joseph H. Wales, Mt. Shasta, Calif.

C. H. Wilson, Glens Falls, N. Y.

TABLE OF CONTENTS

	Page
List of officers	3
Committees, 1944-1945	4
Past presidents	6
In Memoriam	10

PART I. REPORTS

Report of the president; *John Van Oosten*	13
Treasurer's report; *R. P. Hunter*	14

PART II. PAPERS

Standard terms and methods of measurement in fish culture; *James A. Rodd*	19
Infectious diseases among wild fishes; *H. S. Davis*	21
The disinfection and maintenance of trout hatcheries for the control of disease, with special reference to furunculosis; *D. John O'Donnell*	26
Further results from spring and fall plantings of legal sized, hatchery reared trout in streams and lakes of Michigan; *David S. Shetter*	36
A system for recording measurements of fish scales; *Leo Shapovalov*	59
Angling experiments by the Fly Tyers Club at Cornell University; *Dwight A. Webster*	63
The commercial marine fishes, crustaceans and molluscs of the west coast of Mexico; *Milton J. Lindner*	71
The riboflavin and pantothenic acid requirement of brook trout; *Arthur M. Phillips* and *A. V. Tunison*	81
Age and growth of the kiyi, *Leucichthys kiyi Koelz*, in Lake Michigan; *Hilary J. Deason* and *Ralph Hile*	88
Distribution, abundance, and spawning season and grounds of the kiyi, *Leucichthys kiyi* Koelz, in Lake Michigan; *Ralph Hile* and *Hilary J. Deason*	143
Population depletion in brook, brown, and rainbow trout stocked in the Blackledge River, Connecticut, in 1942; *Lyle M. Thorpe, H. John Rayner*, and *Dwight A. Webster*	166
The effect of natural and artificial propagation in maintaining a run of Atlantic salmon in the Penobscot River; *George A. Rounsefell*	188
A technique for controlling infectious diseases in hatchery fish; *Frederic F. Fish*	209
Geochemical interpretation of water analyses from Tennessee streams; *C. S. Shoup*	223

Page

A study of the deep-water cisco fishery of Lake Ontario with particular reference to the bloater *Leucichthys hoyi* (Gill); *Udell Bennett Stone* 230

Food chains and the food cycle in Hawaiian fish ponds.—Part I. The food and feeding habits of mullet (*Mugil cephalus*), milkfish (*Chanos chanos*) and the ten-pounder (*Elops machnata*); *Robert W. Hiatt* 250

Food and the food cycle in Hawaiian fish ponds.—Part II. Biotic interaction; *Robert W. Hiatt* 262

Returns from natural spawning of cutthroat trout and eastern brook trout; *Osgood R. Smith* 281

The physiological effect of sodium chloride upon brook trout; *Arthur M. Phillips, Jr.* 297

Mortality of smelt, *Osmerus mordax* (Mitchill), in Lake Huron and Michigan during the fall and winter of 1942-1943; *John Van Oosten* 310

Variations in nitrogen content and fish production in smallmouth black bass ponds; *Eugene W. Surber* 338

A laboratory study of fish populations; *Hurst H. Shoemaker* 350

A tagging experiment on the fish population of Third Sister Lake, Michigan; *Robert C. Ball* 360

APPENDICES

Certificate of incorporation 372

Constitution and by-laws 373

List of members 377

Instructions for preparing and editing manuscripts for the Transactions of the American Fisheries Society 391

Index to Volume 74 395

PART I
REPORTS

REPORTS OF OFFICERS

THE CANCELLATION OF THE SEVENTY-FOURTH ANNUAL MEETING OF THE AMERICAN FISHERIES SOCIETY

JOHN VAN OOSTEN, *President*

On January 17, 1944, a circular letter was mailed to each member of the Executive Committee requesting his views on whether the American Fisheries Society should meet in 1944 and if so when and where the convention should be held. The majority of the Committee voted to hold a meeting during the week of September 11 at Chicago, Illinois. As the result of this action the President attended a conference in Chicago on March 8, 1944, at which preliminary arrangements for the convention were completed with Mr. P. J. Hoffmaster, President of the International Association of Game, Fish and Conservation Commissioners, and Mr. Livingston E. Osborne, Director of the Illinois Department of Conservation, who graciously consented to act as host not only to our Society but also to the International Association which was scheduled to meet in conjunction with the Society. On March 31 at a second Chicago conference a tentative program was drawn up and the hotel selected, which actions were approved by the Executive Committee at its meeting April 24, 1944, in Chicago. On June 15, 1944, an announcement was issued jointly by the President and Secretary-Treasurer proclaiming the scheduled meeting of the Society on September 13 and 14, 1944.

On June 21, 1944, the Director of the Office of Defense Transportation issued an urgent plea to all organizations to cancel all non-war-connected meetings and earlier the U. S. Department of the Interior, as well as certain states, prohibited all travel by its employees, which included members of the Fish and Wildlife Service, unless it was directly associated with the war effort. In view of these developments another circular letter was sent to the members of the Executive Committee on July 29, and the Committee then voted unanimously to cancel the 1944 convention. Similar action was taken by the International Association.

It is extremely unfortunate that our annual convention had to be cancelled for the third time since the St. Louis, Missouri, meeting in 1941. It is hoped that these unavoidable postponements will not react to the detriment of the Society. The continued publication of *Transactions*, although delayed, will undoubtedly aid in maintaining the interest of our members in the Society and in bridging the gap between our last meeting and the next one to come.

It is with considerable regret that I must also report the resignation in July 1944 of Miss Ethel M. Quee, our very able and genial Assistant-Secretary. Ill health and increased pressure of her regular

duties with the American Wildlife Institute forced Miss Quee to this action. She has served our Society very faithfully and well for many years. We are sorry to have her leave us.

Finally, I also wish to take this opportunity to express the Society's deep gratitude to the American Wildlife Institute which from its beginning has provided the Society without charge office facilities at Washington, D. C., and hotel rooms at its annual conventions for the use of the Executive Committee.

TREASURER'S REPORT

July 1, 1943-June 30, 1944

R. P. HUNTER

GENERAL FUND

RECEIPTS			
Balance on hand July 1, 1943			$1,558.07
Annual dues			
Individuals:			
For the year	1941-1942	$ 27.00	
	1942-1943	168.00	
	1943-1944	768.00	
	1944-1945	271.50	
	1945-1946	6.00	1,240.50
Libraries			
For the year	1941-1942	$ 2.00	
	1942-1943	6.00	
	1943-1944	64.00	
	1944-1945	6.00	78.00
Life			100.00
Clubs and Dealers			
For the year	1941-1942	$ 5.00	
	1942-1943	15.00	
	1943-1944	50.00	
	1944-1945	40.00	110.00
State Memberships			
For the year	1942-1943	$ 60.00	
	1943-1944	440.00	
	1944-1945	40.00	540.00
Sale of *Transactions*			216.90
Sale of *Index*			13.50
Sale of *Reprints*			107.89
Exchange on checks			.40
Total receipts			$3,965.26

DISBURSEMENTS

Printing and binding	$1,518.65
Exchange on checks	4.19
Postage	54.87
Office supplies	12.50
General expense	31.27
Rental of safe deposit box	6.00
Clerical and secretarial	
R. P. Hunter	100.00
Ethel M. Quee	300.00
Premium on fidelity bond	18.75
Total disbursements	$2,046.23

Total receipts General Fund	$3,965.26
Total disbursements General Fund	2,046.23
Balance on hand June 30, 1944	$1,919.03

PERMANENT FUND

RECEIPTS

Balance on hand July 1, 1943	$1,549.05
Interest on savings account	14.93
Mortgage certificates	
Interest	227.08
Principal	*1,062.02
Dividends on Commonwealth & Southern preferred stock	60.00
Balance on hand, June 30, 1944	$2,913.08

INVENTORY

Par value of certificates other than Government Bonds	5,000.00
Par value of 10 shares of Commonwealth Southern preferred	1,000.00
Par value of Government Bonds	1,650.00
Total	$10,563.08

*Includes $761.99 received on Title Guaranty & Trust Company certificate No. 103,553, Bond No. C-7401, Guarantee No. 170,885, constituting final principal payment.

PART II
PAPERS

STANDARD TERMS AND METHODS OF MEASUREMENT IN FISH CULTURE

JAMES A. RODD
Department of Fisheries, Ottawa, Canada

According to official reports and information furnished in response to questionnaires (Rodd and Stapledon, 1941) there is a confusing difference in the meaning of the same term or classification as it is used by Federal and State fishery departments in the United States in describing or listing the output of their fish hatcheries. As the terms or classifications were used in 1941, "fry" had 10 different meanings, "advanced fry" 6, and "fingerlings" 10. There was also a similar lack of uniformity in computation or counting methods. "Fry" were computed in 6 and "Fingerlings" in 5 different ways. Most computation methods were as reasonably accurate as seems possible, but others did not take into account "invisible" or "unobserved" losses.

Corresponding confusion existed in Canada until recently, when in the interests of uniformity, all Canadian Dominion and Provincial Government Departments that are operating fish hatcheries adopted the following standard terms and standard methods of measurement.

STANDARD TERMS

1. *Egg:* The general term "Egg" applies to the egg in all stages of development.

   Sub-Division:

   Green eggs: Eggs from the time they are stripped or spawned until they have become firm and have ceased to absorb miosture.

   Water-hardened eggs: Eggs that are firm and have ceased to absorb moisture.

   Eyed eggs: Eggs in which the eyes or the dark eye-spots are clearly visible.

   Fertile, unfertile, etc.: These terms are self-explanatory.

2. *Fry:* Fish from the time they are hatched until complete absorption of the yolk sac.

3. *Advanced fry:* Fish for a period of two weeks from complete absorption of the yolk sac.

4. *Fingerlings:* Fish from two weeks after complete absorption of the yolk sac until they are one year old from date of hatch.

   Sub-divisions of fish during their first year when they are classified as "fingerlings" is based on age from the time of hatch.

While age is accepted as the primary basis for the sub-division of fingerlings and will be indicated in published reports, each Department or Agency in addition to age is free to give the size, length or weight of its hatchery output or describe it in any other additional way.

5. *Yearlings:* Fish from one to two years old from date of hatch.

6. *Fish older than yearlings* are indicated according to age in years from date of hatch.

Measurement

1. *Eggs:* Volumetric measurement in water based on three or more sample counts of the contents of a unit measure.

2. *Fry:* Computation by estimate checked against egg measurement with egg losses and visible fry losses deducted.

3. *Advanced fry:* In the early stages computation by estimate checked against egg measurement with egg losses and visible fry losses deducted. In the later stages, similar computation checked by sample counts.

4. *Fingerlings:* In the early and medium stages computation by weighing in water based on sample counts. In the later stages with larger fish, computation by weighing in water based on sample counts if the numbers are too large to count, otherwise by actual count.

   Computation by weighing facilitates determination of the quantity and the cost of the food that goes into the production of a pound of fish.

5. *Yearlings and older fish:* By count.

Literature Cited

Rodd, James A., and Charles F. Stapledon
1942 Classification of fish-cultural products and methods of determining the numbers of fish contained in individual allotments. Trans. Am. Fish. Soc., 1941, Vol. 71, pp. 290-293.

INFECTIOUS DISEASES AMONG WILD FISHES

H. S. Davis

U. S. Department of the Interior, Fish and Wildlife Service, Kearneysville, West Virginia

Abstract

It is generally believed that fish diseases are a product of the hatcheries and that they rarely occur among wild fishes. This impression is largely due to the difficulty of detecting and studying diseases in fish under natural conditions. There is good evidence that infectious diseases are quite common among fishes in nature and that they exact a heavy toll each year. The most destructive diseases are caused by bacterial and protozoan infections. Virus diseases may result in widespread epidemics, but the mortality is usually not high. Infections with fungi are not uncommon and may cause considerable mortality. Parasitic worms and copepods, while common, appear to be relatively less harmful.

There is a widespread belief that the average hatchery is a hotbed of disease where ailing fish are the rule rather than the exception and that, in contrast, wild fishes rarely fall victims to infectious diseases. So firmly established is this impression that a well-known investigator stated recently that it may be necessary to establish elaborate quarantine regulations to control the spread of diseases and parasites by hatchery fish.

The writer has no desire to minimize the prevalence of disease at hatcheries, but there is no doubt that this view is a very erroneous one. As a matter of fact, the hatcheries should be quarantined against wild fish, rather than the reverse.

It is easy to understand how the belief that the hatcheries are the fountainhead of disease troubles has become so firmly established. The crowded and unnatural conditions at trout and salmon hatcheries provide an ideal environment for the spread of an infectious disease, and such a disease, when once started, may quickly assume epidemic proportions. Furthermore, hatchery fish are under continuous observation and any serious outbreak of disease can hardly escape discovery. For similar reasons, nearly all studies of fish diseases have been made with hatchery fish and there is the added incentive that control of these diseases is essential for the successful operation of the hatcheries. Naturally, the study of disease has not assumed the same importance in the culture of warm-water fishes, since they are reared under less artificial conditions.

On the other hand, wild fishes are difficult to observe and unless there is a heavy mortality at one time, there is little chance that the presence of diseased fish will be discovered. Ordinarily, weakened fish are destroyed by predators and even if they are not, they quickly sink to the bottom of the stream, lake or pond, after death where they

easily escape detection. Even when there is such a heavy mortality as to attract public attention, the condition is rarely brought to the notice of a qualified biologist before it is too late to determine the cause of the trouble, which is usually attributed to pollution or oxygen deficiency. No doubt, these are frequently the cause of mortality, but it is equally certain that such mortalities may also be due to disease.

We should remember that many ponds and small lakes, especially those left by falling flood waters along our larger streams, provide ideal conditions for the development of infections. As the water recedes, with consequent crowding of the fish, and temperatures rise, such ponds and sloughs provide excellent nurseries for the growth, multiplication and spread of parasitic bacteria, fungi, Protozoa, and other animal parasites, frequently rivalling hatcheries in this respect.

Finally, it may be well to emphasize the obvious fact that none of the diseases which bedevil our fish-culturists orginated at hatcheries. All were introduced, usually on wild fish, and it is fortunate, indeed, that only a small percentage of the diseases that occur on wild fishes have become established at our hatcheries.

The majority of the serious diseases of fishes are caused by bacteria and Protozoa. Infection with fungi may also result in heavy mortalities and epidemics, due to virus diseases are not uncommon. The larger animal parasites such as copepods and worms, while common on wild fishes, rarely become sufficiently abundant, with a few notable exceptions, to seriously affect the health of the host.

It is probable that, in general, bacterial diseases are more lethal to fish than any other type of infectious disease, but our knowledge of these infections is very limited. Plehn, in her manual of fish diseases, describes several bacterial diseases which from time to time cause serious epidemics among various species of fish in European waters and similar epidemics are no doubt fully as common in this country. The writer has received many reports of heavy mortalities of fish in various parts of the United States which appear to have been caused by bacteria. Strange as it may seem, catfishes are apparently among the species most commonly infected and severe mortalities are frequently reported during the spring and summer.

Heavy mortalities in lakes and ponds during the winter and early spring are almost invariably ascribed to oxygen deficiency, but experience with wintering fish in hatchery ponds suggests that in many instances infection with bacteria or Protozoa may be the principal or secondary cause of the mortality. When the fish are discovered, it is too late to determine the cause of death by direct examination. In this connection it is interesting to note that European investigators have found that at temperatures below 50°F. eels and carp are unable to form antibodies and thus develop immunity to an infection.

Furunculosis is the best known bacterial disease of fishes and while it is ordinarily considered a hatchery disease, it causes serious losses

among salmon and trout in European streams. Apparently, it has not become established in our eastern waters, but furunculosis is not uncommon among salmonid fishes in West Coast streams. This is not surprising, since there is evidence that *B. salmonicida*, the causative organism of furunculosis is indigenous to these streams.

Another common bacterial disease among wild fishes is caused by the myxobacterium *Cytophaga columnaris* (Davis). This disease, first observed in fish from the Mississippi River, is known to occur in all parts of the United States and may affect a great variety of species. It is especially prevalent among warm-water fishes and usually follows a slight injury, causing death in a short time. It may also occur in epidemic form and has been responsible for heavy mortalities. In the summer of 1942, for example, the disease caused the death of thousands of white crappie in Coolidge Lake, Arizona. Although more frequently found on warm-water fishes, the bacteria may also infect trout when water temperatures are relatively high. Extensive infections with *C. columnaris* have recently been found on several species of fishes, including adult salmon, in the Columbia and Sacramento Rivers.

Turning to the protozoan diseases, we find that Protozoa are common parasites of hatchery and wild fishes, by far the greater number being known only from the latter. One entire group of Protozoa, the Myxosporidia, are confined almost entirely to fishes only a few species being found in other vertebrates. With one exception, the Myxosporidia are internal parasites and are common in both fresh-water and marine fishes. It is probable that few species of fishes are not at some time infected with Myxosporidia, but for the most part, these parasites appear to do little harm. Sometimes, however, they may be so abundant as to cause extensive injury to the tissues of the host, especially the gills. There is little evidence that myxosporidian parasites have caused serious trouble at hatcheries, although in a few instances this may have been the case. Other internal protozoan parasites are the intestinal flagellates (*Octomitus*) the blood flagellates (*Trypanosoma*) and various species of Coccidia. *Octomitus* is the only one known to occur in hatchery fishes, but there is a possibility that some coccidian might find a congenial environment at our hatcheries and become a serious pest. These parasites invade the lining of the digestive tract, causing extensive destruction of epithelial cells. Fortunately, the blood flagellates are not likely to infect hatchery fish, since they are transmitted by leeches. They may, however, produce a serious disease in wild fish. Some years ago the writer found a sucker in an eastern Washington stream that was so weakened by these parasites that it could hardly swim. It was only by the merest chance that this fish was discovered and there was no means of ascertaining the extent of the mortality from this disease.

Some of the most serious diseases are caused by infection with

ectoparasitic Protozoa which live on the body, fins and gills, and multiply very rapidly. Infections with these organisms are probably second only to bacterial diseases in their injurious effects on both wild and hatchery fishes. Such parasites as *Ichthyophthirius, Chilodon, Trichodina,* and *Costia* are well known to fish-culturists, but they are also common on wild fishes along with many other species which are so far unknown at hatcheries. *Ichthyophthirius* is frequently abundant on fish in sloughs along the Mississippi River and several years ago caused considerable mortality among crappies and sunfishes in a Tennessee Lake. This case is of special interest, since it indicates that so-called improvement devices may produce results which are quite different from those anticipated. The lake in question had been owned by a club for years, but there was no noticeable fish mortality until the spring following installation of brush shelters around the lake shore. It is a reasonable assumption that these structures were indirectly responsible for the mortality, since they would provide ideal conditions for the spread of this parasite.

The various species of *Trichodina* are common parasites of wild fishes. They usually occur on the gills, but may be found on the surface of the body and fins. When abundant they may cause serious injury and even the death of the host. An indication of the frequency with which these and other protozoan parasites may occur on fish and our ignorance regarding them is furnished by a pearl minnow (*Margariscus margarita*) which was harboring on its gills three species of *Trichodina,* a scyphidian, an encysted ciliate and an ectoparasitic myxosporidium (*Chloromyxum sp.*), a total of six species, none of which have been described. The gills of a crappie supported three species of flagellates, all previously unknown. While such cases are no doubt exceptional, it is evident that ectoparasitic Protozoa are among the most common parasites of fresh-water fishes.

Among the parasitic fungi the fish molds are the most common and best known. They infect both wild and hatchery fish and because fungused fish are so conspicuous, the disease is probably better known to the average person than any other fish disease. It was formerly thought that only injured fish or those weakened by disease became infected, but it is now recognized that some species of fungi may attack healthy, uninjured fish, which greatly increases their harmful potentialities.

Not to be outdone by the higher vertebrates, fish have their own peculiar virus diseases. The most common and best known of these is the so-called lymphocystis disease which is characterized by nodular growth on the body and fins and also on the viscera. The disease attacks both fresh-water and marine fishes, the sunfishes apparently being particularly susceptible. Although it frequently occurs in epidemic form, it is not as fatal as most infectious diseases. Another virus disease which causes the formation of white eruptions composed

of epithelial cells on the body of smelt and pickerel is not uncommon, but practically nothing is known about it.

Parasitic worms, both external and internal are common on wild fishes, but do not appear to cause serious injuries unless present in large numbers. They may, however, reduce the food value of the host, even though its health is not materially affected. Larval flukes may attack the eyes, causing "popeye" and blindness, and gyrodactylid worms may infect the gills, paving the way for secondary invaders as well as injuring the delicate tissue directly. In much the same way parasitic copepods may become a serious pest.

It is believed that in spite of our limited knowledge regarding infectious diseases among wild fishes, the conclusion is justified that such diseases are not uncommon and that they cause the death of large numbers of fish each year. Probably the greatest mortality is among young fish where it is least likely to be noticed. It is well known that there is usually a heavy mortality among fry and young fingerlings, but the cause of this mortality is still a matter for speculation. No doubt a large proportion are destroyed by predators, but there is evidence that disease may also be an important factor. For example, a large percentage of smallmouth bass fry collected from the nests of wild fish were infected with Ichthyophthirius, gyrodactylid worms, and Myxosporidia. Possibly this was an exceptional case, but it certainly indicates a fruitful line of investigation. In fact, there is probably no field of fishery research which promises more for the effort expended than a study of the diseases of our wild fishes.

THE DISINFECTION AND MAINTENANCE OF TROUT HATCHERIES FOR THE CONTROL OF DISEASE, WITH SPECIAL REFERENCE TO FURUNCULOSIS

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ABSTRACT

Detailed methods are presented for the control of disease in trout hatcheries, especially furunculosis, through the elimination of all fish, thorough disinfection of the hatchery, the rebuilding of a new stock of disease-free fish, and the maintenance of disease-free conditions throughout all future operations.

Procedures are given for eliminating diseased stock and for disinfecting raceways, ponds, buildings and all movable equipment with a solution containing 200 p.p.m. chlorine. All chlorine solutions are maintained at 200 p.p.m. for a minimum period of one hour. Directions for maintaining a hatchery in a disease-free condition and preventing recontamination after disinfection, are presented.

The neutral acriflavine method of disinfecting trout eggs is described, as well as directions for the operation of a chlorine sterilizer unit. The sterilizer unit is used for the routine disinfection of pieces of small equipment.

A section is devoted to special technics which describe the preparation of acriflavine solutions, buffers, chlorine solutions and the malachite green and copper sulphate methods of controlling fungus on trout eggs.

INTRODUCTION

Within recent years, with the increase in production of legal trout at a comparatively high cost, the necessity of preventing and controlling fish diseases has assumed major importance. Our knowledge of the methods of preventing and eliminating disease has increased considerably but there is still much to be learned. Some diseases are controlled quite easily, while others, such as furunculosis, caused by *Bacterium salmonicida*, has failed to yield to experimental treatments. The only known method of absolute control of *B. salmonicida* involves the complete elimination of all fish from a hatchery, thorough disinfection of the hatchery, the rebuilding of a new stock of disease-free fish, and the maintenance of disease-free conditions throughout all future operations. Unfortunately, however, this method is practical only at those hatcheries having a controlled water supply, that is, originating in wells or springs that can be kept free of fish. The disinfection of hatcheries utilizing river water, or other public waters, would be inadvisable because of the constant danger of new infections from fish in these waters. The present report attempts to give detailed procedures for completely disinfecting a hatchery and its subsequent operations as a disease-free unit.

Method of Disinfection

Elimination of fish.—If an epidemic is in progress it is desirable to remove all fish by seining, and to destroy them by burial with lime or by burning. All stragglers left in an open area will be destroyed by chlorine, but all blind pockets or tile lines should be explored and disinfected. If an epidemic has passed and there is only the possibility of some carriers remaining, the trout may be planted in a selected stream. Such a stream should be, small, heavily-fished and not a tributary of a better or important stream. However, the second procedure should not be practiced unless there is strong objection to the destruction of valuable (monetary) fish. There are a few records of furunculosis in wild stock in isolated streams of the midwest and the planting of diseased fish could very easily aggravate "normal" conditions and produce an epidemic of serious proportions with the result that the native stock would be reduced markedly.

Chemicals.—Chlorine, because of its efficiency in killing pathogenic organisms and its low cost has been found to be the most desirable chemical disinfectant for hatchery use. It is available in powder or fluid form which liberate various amounts of "available" chlorine. These powders and fluids are found on the market under such names as "HTH-15," "HTH-65," "B-K powder," "B-K solution," "Klenzade XY-10," "Klenzade X-15," "Roman Cleanser 3 Percent," "Roman Cleanser 5.25 Percent," "Chlorox" and many others. In Wisconsin, the "Klenzade" solutions have been used in quantities. The use of the fluids in quantity has one disadvantage in that they are packaged in glass containers and some breakage is unavoidable. The only disadvantage of dry powders, is that they are more expensive than solutions, however, this may be out-weighed by their increased stability in storage and ease of use.

The concentration found to be most effective in all hatchery disinfection work is 200 p.p.m. chlorine. When clean surfaces are kept moist with such a concentration, disease producing organisms are killed in less than 30 minutes. Although it is desirable to maintain the solution at full strength, occasionally this is impossible, such as when treating raceways, due to dilution, but under no conditions should the concentration fall below 100 p.p.m. At 100 p.p.m. disease producing organisms are killed in one hour or less. Mud, muck and other organic matter dissipates chlorine at a rapid rate and, therefore, as much as possible of such material should be removed.

Preparation for Treating Hatcheries.—Before starting the actual chemical disinfection of the hatchery a number of preliminary operations are necessary. All raceways and troughs are measured for capacity and calculations made of floor surfaces in the buildings, allowing for 3 inches of solution on all floors. Then, knowing the full capacity of ponds, raceways, tanks, and allowance for 3 inches on floors and after determining the type of chlorine solution or powder

to be used, calculations are made of the quantity needed to produce a concentration of 200 p.p.m. In the event that the chlorine solution will run into fish-bearing waters after leaving the hatchery, neutralization will be necessary to render the chlorine inactive and harmless. Commercial sodium thiosulphate, "Hypo," is used as a neutralizer, 5.6 grams being required to neutralize each gallon of 200 p.p.m. chlorine solution.

All loose equipment should be brought out of storage rooms and scrubbed thoroughly with warm water and soap if possible and left near a raceway for chemical disinfection later. Such equipment includes buckets, pans, small troughs, tubs, end screens, seines, extra splash boards, and any others. During this operation much worn out equipment may be found and destroyed by burning or some other method. Hatching and rearing troughs should be scrubbed clean. The side walls of all raceways should be scrubbed and the bottoms raked. Particular attention should be given to any left-over fish food, pond scum or any other substance of similar origin.

Chemical disinfection.—Since variations in the actual administration of the chlorine will occur at different hatcheries, only general procedures can be given. It is desirable that the actual disinfection be carried out in such a manner that the full strength of chlorine will be maintained for at least 1 hour and the concentration of not less than 100 p.p.m. will be maintained for several hours. Most hatcheries are so large that complete disinfection cannot be completed in 1 day, the treatment must be carried out by areas or blocks, starting at the upper end of the hatchery. Before adding chlorine, all ponds, raceways, and troughs are drained down. Additional splash boards are provided in certain sections to allow raising of the water to the top of each section. Rearing troughs are plugged so that they will overflow. After being drained, the splash boards are installed and the water allowed to rise until the particular section is about half-full. One-half of the calculated amount of concentrated chlorine is then emptied into the raceways, and stirred in thoroughly by dragging a loose coil of "chicken wire," which has been weighted with pipe, back and forth along the bottom. When the water has risen within 2 inches of the top of the splash boards the remaining chlorine concentrate is then emptied into the section. The chlorine is again stirred-in thoroughly by dragging the coil of "chicken wire." The same general procedure is continued until the entire raceways system, including all springs, are completely filled with the water containing chlorine. The operation of a small outboard motor in a raceway is also helpful in circulating the chlorine solution.

In treating the inside of the hatchery buildings all drain outlets must be blocked. Calculated amounts of concentrated chlorine are allowed to flow gradually into the head trough and supply the various rearing troughs, which are allowed to fill and overflow until there is

3 inches of chlorine solution on the floor. The chlorine solution is taken from the floor by the use of a pump and hose line and the sides and bottoms of all tanks, tank racks, side walls and ceiling, head trough and any other dry equipment are kept moist for a period of one hour. The same procedure must be used in all rooms and buildings, with special attention being given to the meat room and refrigerator. When the hatchery is disinfected in sections, the work should be so planned and timed that all buildings, springs, and raceways contain approximately maximum chlorine at the same time. This is necessary to insure that no undisinfected waters are run over part of the system that has already been disinfected and thus dilute the chlorine solution. While a maximum concentration of chlorine is being maintained in the raceway system, all loose equipment such as pails, tubs, trays, splash boards and other material may be placed in the raceway for disinfection. Care must be taken to see that wooden equipment is kept submerged. Throughout the course of the disinfection a check should be made on the approximate chlorine content of the water by using the ortho-tolidine test or "LaMotte" chlorine-test papers. If possible, iodometric titrations should be made at intervals for residual chlorine. If any section shows a concentration of less than 100 p.p.m. chlorine after one hour, such solutions must be fortified with additional chlorine.

Maintenance of Hatcheries

After a hatchery is completely disinfected and disease-free, the prevention of recontamination is of prime importance.

The movement of *any life fish* into the hatchery should be absolutely forbidden and production should be started with disinfected eggs. All eggs which are received should be disinfected with 0.05 percent neutral acriflavine solution (buffered to pH 7.6) for a period of 30 minutes. The hatchery must be protected from the water, packing, cases of shipped eggs and hands of the handlers of such eggs and from the shipping truck. The methods used in disinfecting trout eggs are discussed in the next section.

All shipped-in equipment should be disinfected thoroughly before it comes into contact with clean hatchery equipment and water. All loose equipment and the workers' hands should be cleaned and sterilized at intervals. The liberal use of warm water and soap is recommended. All trucks and equipment coming to the hatchery to haul fish should be disinfected on the road before entering the hatchery. The drivers and helpers should not be allowed to assist in loading or even to visit any part of the hatchery. The spread of furunculosis can be prevented only by rigid cleanliness and operating-room methods, as used in hospitals. A "KEEP IT CLEAN" motto should be adopted and fish-culturists impressed with the idea that a minor "slip up" in cleanliness may nullify all previous efforts.

The Method of Disinfecting Trout Eggs

Since 1938, neutral acriflavine has been employed in the routine disinfection of trout eggs coming into hatcheries. The acriflavine treatment is used as a means of preventing the introduction of furunculosis into a hatchery when eggs are transferred from other hatcheries. During the past five years, some 30,000,000 eggs have been given this treatment in the Wisconsin hatcheries. Although variations in the method will be necessary at some hatcheries, a general procedure is as follows:

Preparation of Equipment.—Hospital cleanliness must be employed in all phases of treatment. Scrub the hatching trough thoroughly until all dirt and debris is removed. Plug tank outlets so that the tank can be filled to overflowing. Calculate the capacity of the tanks. Fill all of the tanks to overflowing with 200 p.p.m. of chlorine solution. All solutions overflowing onto the floors must be prevented from flowing into any water containing fish. Let the chlorine solution remain in the tanks from 15 to 30 minutes. Then neutralize the chlorine with sodium thiosulphate to the ortho-tolidine colorless point. After neutralizing, the solution may be safely flowed through waters containing fish. After it is disinfected, extreme care must be exercised with all equipment to prevent its re-contamination.

Handling the eggs.—Before beginning to handle the eggs it is necessary that a biologist, or some other designated supervisor, assign duties to the hatchery personnel. The hatchery foreman should "temper" the eggs and measure them on trays in the usual manner. The eggs should be picked with the utmost care before treatment, and every clouded and spotted egg must be removed. One competent person should be responsible for the picking of the eggs, stacking them for treatment and draining them to the "dripping point." After draining it is his additional duty to place the trays in the special clamps which are used in the treating box. The treating box ordinarily is of such size that from 17 to 22 trays, depending upon their thickness, can be treated at one time. The biologist or supervisor is responsible for all disinfection with chlorine, for the disinfection of the eggs, and for placing the eggs in the hatching troughs. During the period of any egg treatment, the hatchery personnel should be under the direct supervision of a trained supervisor or the biologist. The hands of all workers should be washed frequently with strong soap and water and after rinsing they should be dipped several times in 200 p.p.m. chlorine solution. Too much stress can not be made on the necessity of using aseptic measures throughout the treatment.

A hatchery should be protected from the egg cases and untreated eggs. After tempering, the eggs are placed in trays as usual. The trays are drained and placed in the special clamp, together with one top tray, and they are then ready for treatment.

Preparation of acriflavine.—The size of the box ordinarily used for the treatment is an inch larger on all sides than the ordinary hatchery tray and of such depth it will hold 70 liters of dye solution plus 17 to 22 trays of eggs without overflowing. Since the stack of trays to be treated is somewhat buoyant it is necessary that some means be provided of holding them under the solution. This may be accomplished by placing a board across the topmost tray and placing a pail of water or some similar weight on the board. The treating box is constructed of galvanized sheet metal reinforced with strap iron, all of which is then painted aluminum. The treating box may be made of wood, tightly caulked and asphalted and of such size as to accommodate trays of different dimensions. (See section on Special Technics for the preparation of acriflavine, buffer and chlorine by units.) Seventy liters of water are measured into the treating box and 700 ml. of 100X buffer are added. The buffer should be such that the final product (a 1:100 dilution) will have a hydrogen ion concentration of approximately pH 7.6. The pH of the solution should be determined colorimetrically or electrimetrically and corrected to pH 7.6. Thirty-five grams of neutral acriflavine are added to the water making a 1:2,000 solution of the dye. Instead of using the dry powder, which should be dissolved in a small amount of hot water, it may be more convenient to add 1,000 ml. of 3.5 per cent acriflavine solution.

Treatment of eggs.—The stack of 17 to 22 trays is tipped toward one corner and allowed to drain into a chlorine tub until the water falls in drops, *i.e.* to the "dripping point." The trays carrying the eggs are then lifted by the clamp and placed in the treating box, making sure that the top tray is submerged. A weight should be placed on the top to keep the trays submerged. About every 5 or 10 minutes the stack of trays should be moved up and down to turn the eggs and expose all surfaces. The eggs are allowed to remain in the dye for a period of one-half hour. After carefully scrubbing and disinfecting the hands and using aseptic precautions, the trays are removed, drained over the treatment box, and placed in the newly-disinfected hatching trough. After the treatment of each lot of 100,000 eggs, the dye solution is reinforced with 7 grams of dry acriflavine or with 200 ml. of the 3.5 per cent solution. From experimental tests it has been found that 1,000,000 trout eggs can be treated with the same solution provided it is reinforced after each lot of 100,000 eggs.

Operation of Chlorine Sterilizer Unit

A chlorine sterilizer unit is used at various points around the hatchery for the routine disinfection of pieces of small equipment, such as nets, scaps, pails, pans, brushes, feathers, pickers, and other implements used in the care and handling of fish and fish eggs. The unit consists of an open-top, leak-proof container which will be partially filled with a chlorine solution. This sets in a larger container

which holds a lesser amount of sodium thiosulphate which will neutralize the chlorine solution in the event of spilling, leakage or breakage of the inner container. The unit may consist of different sizes of barrels, or be constructed of wood, metal or concrete. Regardless of the material used, all surfaces exposed to the solutions should be coated with tar or asphalt before use. The size may vary from very small, for disinfecting small pieces of equipment, to a very large unit, suitable for seines, tubs and like equipment. For greater convenience, a valve may be provided to drain the chlorine container into the outer unit containing the thiosulphate neutralizer. An additional valve may be provided to drain the neutralized chlorine and thiosulphate solution from the outer unit. It should be stressed that chlorine is *very toxic to fish* and the solution should never be drained off unless neutralized. The sodium thiosulphate is used in tenfold strength as a safety factor.

Filling Unit.—Fill the *outside* container with 11.8 ounces (334.5 grams) of sodium thiosulphate (commercial) for each 10 gallons of chlorine solution present in inner container. Add enough water to dissolve the thiosulphate.

Fill the *inner* container to two-thirds capacity and for each 10 gallons of water add 9 ounces liquid chlorine containing 3 per cent available chlorine. The resulting solution will have the required strength of 200 p.p.m. of chlorine. A number of other chlorine containing agents of varying strength may be used and these are listed in the section on Special Technics.

Maintainig the unit.—The strength of the chlorine solution will decrease with usage and an average of one-half of the original strength is lost each week. Therefore, on the eighth, fifteenth and twenty-second days after the unit is started, one-half of the original amount of the chemical used should be added to the chlorine container. The sodium thiosulphate will not lose its strength and need not be changed except at 30-day intervals when the entire unit is renewed.

Renewing the unit.—Pour the solutions back and forth between the outer to the inner containers until the chlorine is completely neutralized. Neutralization may be checked with the "LaMotte" starch-iodide chlorine test papers (which are obtained from the LaMotte Chemical Products Co., Baltimore, Maryland) or by the orthotolidine test. By dropping a few drops of orthotolidine in the solution, the presence of chlorine may be determined, because the drops turn a brownish color upon contact, if chlorine is present. If no color reaction is obtained, the chlorine is completely neutralized. After the containers are drained of the neutralized solutions, the entire unit must be inspected for leaks. The outer and inner containers are then refilled and started anew.

Using the unit.—All equipment should be cleared of debris before being placed in the disinfecting unit. Nets, pails, scaps and other

implements must remain in the chlorine solution for at least one hour to assure sterilization. When the same equipment is used on different lots of fish or eggs it should be sterilized for 60 minutes between use on each.

Special Techniques

Preparation of chemicals.—Because conditions vary considerably from hatchery to hatchery and more especially the sizes of trays and other equipment varies from state to state, it seems desirable to explain the preparation of chemicals by units which may be adapted to these variations.

Acriflavine.—For 0.05 per cent (1-2000) solution of acriflavine use any of the following:

(a) 19 (18.92) grams of acriflavine powder to 10 gallons of water.
(b) 5 grams of acriflavine powder to 10 liters of water.
(c) 143 ml. of 3.5 per cent acriflavine to 10 liters of water.

To prepare 3.5 per cent acriflavine, dissolve with slight heat one ounce of acriflavine powder in 810 ml. of water.

Clark buffer.—In all egg-treating solutions, 100 ml. of 100X buffer are used for each 10 liters of solution. Clark's 100X buffer is prepared by weighing out 680.7 grams of KH_2PO_4 (Sorensen's phosphate) and 187.2 grams of NaOH. The chemicals are placed in a large heat resisting flask and water is added to make one liter.

Chlorine solutions.—In the preparation of chlorine solutions containing 200 p.p.m. of chlorine, the following amounts of chemical are added for each ten gallons of water. If other products are used, calculations of amount can be made from the per cent available chlorine as given on the labels.

"Klenzade:"

XY-10 (8 per cent available chlorine)—3½ ounces liquid measure.
X-15 (11 per cent available chlorine)—2½ ounces liquid measure.

"Roman Cleanser:"

3 per cent available chlorine—9 ounces liquid measure.
4 per cent available chlorine—7 ounces liquid measure.
5 per cent available chlorine—5½ ounces liquid measure.

"HTH" Powder:

15 per cent available chlorine—1.87 ounces (53.12 grams).
50 per cent available chlorine—0.56 ounces (15.94 grams).
65 per cent available chlorine—0.43 ounces (12.26 grams).

"B-K" Powder:

50 per cent available chlorine—0.56 ounces (15.94 grams).

Treating eggs for fungus.—The costly part of trout egg operations consists of the handling and removal of fungused eggs. Two treatments have been developed which inhibit the growth of fungus or in many instances completely eliminates its growth on incubating trout eggs. Such reduction results in a great saving of labor on all eggs since there is no necessity for frequent picking.

The procedure treating with malachite green is simple, and merely involves the daily addition of a basic dose of malachite green stock solution to the hatching troughs. The stock solution is made by dissolving 2 grams of malachite green in 1 gallon of water. The procedure involves the pouring of 2 ounces of the stock solution into the head slot of the hatching trough and an additional 1 ounce in the slot mid-way down the trough. This basic treatment is ordinarily given every other day but may be given daily without any harmful effects upon the incubating eggs.

The use of copper sulphate for preventing fungus on trout eggs is equally as effective as malachite green but must be used with more caution. Ordinarily the dose is approximately one ounce of saturated copper sulphate solution, however, *a basic dose must be established for each hatchery* since hatcheries vary considerably in the hardness of water. In general, less copper sulphate solution will be required in soft waters and more in hard waters.

The basic dose is determined as follows: Early in the spawning season 4 trays of eggs are selected from one lot of eggs taken on the same day and by the same spawner. Each tray is placed in a single compartment at the lower end of 4 hatching troughs. Every other day the copper sulphate solution is placed in the slot above each compartment. One tray is untreated and serves as a control, one is treated with ½ ounce of the solution, one with 1 ounce and the fourth with 1½ ounces. Accurate records are kept of each tray, and the tray having the lowest loss will indicate the proper basic dose. After the basic dose is established, that amount of saturated copper-sulphate solution is added to the head slot of the egg trough and one-half the basic dose is added to the slot halfway down the trough. Further experimentation and observation will indicate the frequency of dose, whether daily, every other day, twice a week, or once a week.

Although any quantity of saturated copper sulphate may be prepared, the basic procedure is that of allowing one pound of copper sulphate to dissolve in one quart of boiling water. The use of an enameled pan or bucket is absolutely necessary. Pour the warm solution into glass storage jars and allow to cool. While cooling a large amount of copper sulphate will crystallize out and leave a saturated solution.

FURTHER RESULTS FROM SPRING AND FALL PLANTINGS OF LEGAL-SIZED, HATCHERY-REARED TROUT IN STREAMS AND LAKES OF MICHIGAN[1]

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ABSTRACT

Further tagging experiments in Michigan with spring and fall plantings of brook trout (*Salvelinus f. fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Salmo gairdnerii irideus*) from which recoveries were made during the 1942 trout season confirmed the conclusion that spring release of adult or near-adult hatchery-reared brook trout and rainbow trout is more desirable than the fall planting of fish of a similar size. In some instances fall stocking of brown trout may furnish as good fishing in the following seasons as does spring planting.

Recoveries of planted fish past the first season of availability ranged from 0.0 to 2.5 per cent in the second season and from 0.0 to 0.5 per cent in the third season.

In either spring or fall planting of legal-sized fish, no advantage was gained by scattering the fish widely over the stream areas stocked.

Eighty five per cent or more of the planted trout recovered were caught within 10 miles of the point of release, regardless of the season or method of planting. Brown trout moved the least and rainbow trout the most. About one-fourth of the brook trout tended to move 3 to 10 miles downstream, and the majority of the remainder were caught within 3 miles of the locality of release. More rainbow trout than any other species were recaptured 10 or more miles from the point of release.

Fall plantings of adult brook trout in lakes were recovered at the rate of 56.7 per cent (range, 13.0 to 88.1 per cent). Unfortunately, a small percentage of the anglers removed an average of 89.4 per cent of the total catch during the opening weeks of the trout season. The average recovery from two spring plantings of brook trout in East Fish Lake in Michigan was 68.5 per cent.

A brief review of the literature substantiates the conclusions reached as a result of the Michigan experiments. Differences in experimental procedure are pointed out, and some reasons are offered for the failure of fish planted in streams in the fall to survive the winter season.

INTRODUCTION

Previous experiments described by Shetter and Hazzard (1941, 1942) demonstrated that, in the majority of Michigan trout streams, from two to six times as many hatchery-bred trout were caught from spring plantings as were caught from plantings made in the fall of the year. As will be pointed out later, this conclusion is, in general, consistent with the results of other investigations in Michigan and in other trout streams of the United States. In lakes where suitable thermal and chemical conditions for trout exist, we found that legal-

[1]Contribution from the Michigan Institute for Fisheries Research.

sized rainbow trout might be planted in the fall of the year with the expectation that from 20 to 70 per cent would be recovered by anglers in succeeding seasons.

This report presents additional information, from data gathered chiefly during the 1942 trout season, on the success of planting adult hatchery-reared trout at different seasons in Michigan streams and lakes. Evidence available on the percentages of marked fish planted which were taken by anglers in the second and third season after release is included, as well as a comparison of the relative merits of "spot" and "boat" planting. An analysis is presented of the movements of the hatchery-reared trout after release in the fall of 1941 and the spring of 1942. A brief review is given also of the results of other investigators on the general subject of planting trout of legal size.

Six streams, located in different sections of Michigan, were planted with jaw-tagged trout. In the lakes studied, where trout were already present, the fish in the plantings were fin-clipped to make the hatchery trout recognizable. In lakes where trout were not found previously, and which were planted with trout for the first time, marking was unnecessary. The 1942 data on the recoveries of marked fish obtained from the streams were in part furnished voluntarily by cooperative anglers while others were secured through the efforts of members of the Fish Division and Field Administration Division.

Fishermen were made acquainted with the purpose of the tagging experiments and their locations through the use of stream-side posters, newspaper publicity, and a descriptive paragraph in the fishing-law summary provided with each license. From the content of numerous letters reporting tag recoveries, it appears that all three forms of publicity aided in securing tag returns from anglers.

Financial considerations, and also a lack of trained personnel, made it impossible to establish creel censuses on the streams studied in 1942. Therefore the total catch in any of the sections of streams planted with tagged fish is not known. Since the trout released at both seasons were under the same angling pressure, the relative numbers of fish reported from the spring or fall planting are significant in the determination of the proper time of release, even though not all tagged fish caught were reported.

The data on the lakes were obtained either through complete creel censuses or censuses limited to the opening week-end or opening day of the trout season.

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Results from Plantings in Streams

Brook trout.—Five hundred jaw-tagged brook trout (*Salvelinus f. fontinalis*) were released in the fall of 1941 and the same number in the spring of 1942 in the West Branch of the Sturgeon River just south of the town of Wolverine in Cheboygan County (Table 1). Of the fall planting, four (0.8 per cent) were later caught and reported, and of the spring planting, 18 (3.6 per cent) were reported as captured by angling. In comparison with previous planting experiments with brook trout, these releases yielded a relatively small number of returns, for which fact no definite reasons can be given. Lighter angling pressure on this stream in 1942 than in previous seasons may have influenced the results.

On the Middle Branch of the Ontonagon River (Gogebic County), 150 legal-sized brook trout were tagged and released at each season. Twelve returns, or a recovery of 8.0 per cent, were reported from the 1941 fall planting in the 1942 fishing season, while 17 (or 11.3 per cent) were returned from the 1942 spring planting.

For the two streams combined, an average recovery of 2.5 per cent was made from the 1941 fall plantings, and of 5.4 per cent from the spring plantings (release of 650 tagged fish at each season).

Rainbow trout.—Two trout streams in the extreme southwestern part of Michigan (Portage Creek in Kalamazoo County on the outskirts of Kalamazoo, and Dowagiac Creek in Cass County) were included in the experiments of 1941-42, since it seemed possible that the over-the-winter mortality of adult fish might be much lower than that previously noted in streams farther north where the winters are more severe. Accordingly, fall and spring plantings of legal-sized rainbow trout, *Salmo gairdnerii irideus*, and brown trout, *Salmo*

TABLE 1.—*Results from fall and spring (pre-season) planting of tagged trout of legal size in Michigan streams, based on fish reported captured during the 1942 trout season*

[Figures in parentheses indicate average total length in inches]

Stream	Brook trout						Rainbow trout						Brown trout					
	Number planted		Number recovered		Percentage recovery		Number planted		Number recovered		Percentage recovery		Number planted		Number recovered		Percentage recovery	
	1941 Fall	1942 Spring	1941 Fall	1942 Spring	1941 Fall	1942 Spring	1941 Fall	1942 Spring	1941 Fall	1942 Spring	1941 Fall	1942 Spring	1941 Fall	1942 Spring	1941 Fall	1942 Spring	1941 Fall	1942 Spring
Portage Creek	.....	.....	.....	.....	.....	.....	100 (7.1)	100 (9.6)	2	17	2.0	17.0	25 (6.4)	25 (9.8)	0	3	0.0	12.0
Dowagiac Creek	.....	.....	.....	.....	.....	.....	250 (6.8)	250 (9.5)	3	28	1.2	11.2	50 (6.4)	50 (10.2)	0	2	0.0	4.0
Baldwin Creek	.....	.....	.....	.....	.....	.....	250 (7.8)	250 (8.4)	14	28	5.6	11.2	250 (8.9)	250 (8.3)	18	16	7.2	6.4
Main Au Sable	.....	.....	.....	.....	.....	.....	250 (9.5)	250 (10.6)	23	51	9.2	20.4	250 (8.3)	250 (9.0)	18	32	7.2	12.8
West Branch, Sturgeon	500 (8.4)	500 (9.2)	4	18	0.8	3.6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Middle Branch, Ontonagon	150 (6.9	150 (9.1)	12	17	8.0	11.3	150 (6.8)	150 (8.2)	3	11	2.0	7.3	.....	.....	.....	.....	.....	.....
Totals or weighted averages	650	650	16	35	2.5	5.4	1,000	1,000	45	135	4.5	13.5	575	575	36	53	6.3	9.2

trutta, were made in each. Dowagiac Creek, although ditched for a drain throughout most of its length, has favorable trout habitats and temperature conditions in the vicinity of the city of Dowagiac. Portage Creek has a normal stream channel and favorable temperatures for about 3 miles south of the Kalamazoo city limits.

In Portage Creek the results from planting 100 tagged rainbow trout at both seasons of the year were as follows: percentage of recovery by anglers on fall-planted fish, 2.0 per cent (Table 1); on spring-planted fish, 17.0 per cent.

In Dowagiac Creek 250 tagged rainbow trout were planted in the fall of 1941, and a like number in the spring of 1942. During the 1942 trout season, three (1.2 per cent) were recovered from the 1941 fall planting, and 28 (11.2 per cent) were reported as recaptured from the 1942 spring planting.

From plantings of 250 tagged rainbow trout each in the spring and in the fall in Baldwin Creek (Lake County), twice as many (28 or 11.2 per cent) were recovered from the spring introduction as from the fall planting (14 or 5.6 per cent) during the 1942 trout season.

The stocking of 250 tagged rainbow trout both in the spring and the fall in the Main Au Sable River (Crawford County) just below the town of Grayling yielded the following results during the 1942 trout season: from the fall planting of 1941, 23 recoveries (9.2 per cent); from the spring planting of 1942, 51 recoveries (20.4 per cent).

In the Middle Branch of the Ontonagan River 150 tagged rainbow trout were planted at each season. Three recaptures (2.0 per cent) were reported during the 1942 season from the fall planting of 1941, and 11 recoveries (7.3 per cent) were made from the spring planting of 1942.

The trend of the results on the two southern streams (Portage Creek and Dowagiac Creek) was the same as for the northern rivers. Several times as many tagged rainbow trout from the spring plantings as from fall releases appeared in the anglers' catches in the 1942 season (see Table 1).

The combined results from the five streams were as follows: 1,000 tagged rainbow trout were planted at each season; 4.5 per cent of the fish of the fall planting of 1941 were recovered during the 1942 season, and 13.5 per cent of the spring planting (or three times as many) were recovered during 1942.

Brown trout.—Experiments which involved the planting of tagged, legal-sized, hatchery-bred brown trout were conducted on four streams. In the two southernmost streams (Portage Creek and Dowagiac Creek), no recoveries were reported during the 1942 season from the fall plantings of 1941. Similar plantings in the spring of 1942 yielded 12.0 and 4.0 per cent respectively to the 1942 anglers reporting on those streams.

In Baldwin Creek, 250 tagged brown trout were planted at each season. During 1942 more fall-planted fish than spring-planted fish

were reported for the first time in the writer's experience (18 or 7.2 per cent from the 1941 fall planting and 16 or 6.4 per cent from the spring planting).

Two hundred fifty tagged brown trout were planted in the Main Au Sable just below the town of Grayling in the fall of 1941 and the same number in the spring of 1942. During 1942, 18 (7.2 per cent) of the fall-planted fish were reported as recaptured, while 32 (12.8 per cent) of the spring release of 1942 were recovered.

A comparison of the number of recoveries of brown trout from the fall and spring plantings in the southern and northern streams indicates that the survival from fall stocking was actually the poorer in the southern waters; in fact, only spring-planted brown trout have been recaptured. However, the number of brown trout used in the southern streams was small, and the average size of the fall-planted fish was not as large as was desirable. These factors may have influenced the results with brown trout in these two streams.

The combined results of the experiments with brown trout of legal size were as follows: fall plantings of 1941—36 (6.3 per cent) of 575 fish were recovered; spring plantings of 1942—53 (9.2 per cent) of 575 fish were recaptured.

"Carry-over" or Survival of Hatchery-reared Trout Through One or More Seasons

A summarization of the results of almost all recent plantings of marked legal-sized hatchery-reared trout is presented in Table 2. Data from the West Branch of the Sturgeon River and Portage Creek have not been included as no reports of recoveries of tagged fish have been received other than those obtained during the 1942 trout season (the first season of availability). Information from Kinne Creek, a privately-owned trout stream on the properties of the Wingleton Club in Lake County, has been included.

Study of the table indicates that, as might be expected, the largest percentage of the planted fish is recovered during the first season of availability regardless of the season of planting. The data from Kinne Creek probably represent the maximum "carry-over" which could be secured. Members of the Wingleton Club are required by their own rules to record each day's catch in a book kept in the icehouse. The stream is blocked quite efficiently near its confluence with the Pere Marquette River by a self-cleaning rotary screen which keeps all fish planted in Kinne Creek in the stream until removed by angling or by natural death. Here small but significant percentages of recovery in the second season after planting have been noted—from 0.4 per cent of a planting of 250 rainbow trout to 2.5 per cent of a planting of 203 rainbow trout. Other recoveries were 2.5 per cent of a release of 201 brown trout and 2.0 per cent from a planting of 100 brook trout. These percentages of recovery during the second season after planting are, for the most part, higher than encountered in the

TABLE 2.—*A comparison of the results from spring and fall plantings of brook, brown, and rainbow trout in Michigan streams*

[Figures in parentheses indicate percentages or recovery. Where no recovery was made the corresponding place in the table has been left vacant]

Stream	Species and season when first became available	Number planted		Number recovered first season		Number recovered second season		Number recovered third season	
		Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
Main Au Sable	Rainbow '41	499	471	98 (19.6)	51 (10.8)	3 (0.6)	1 (0.2)	.....	.....
	Rainbow '42	250	250	51 (20.4)	23 (9.2)	1 (0.4)	.....	.....	.....
	Brown '41	500	500	76 (15.2)	40 (8.0)	2 (0.4)	1 (0.2)	.....	2 (0.4)
	Brown '42	250	250	32 (12.8)	18 (7.2)	1 (0.4)	2 (0.8)	1 (0.4)	.....
Baldwin Creek	Rainbow '41	500	498	51 (10.2)	38 (7.6)	2 (0.4)	1 (0.2)	.....	.....
	Rainbow '42	250	250	28 (11.2)	14 (5.6)	1 (0.4)	.....	.....	.....
	Brown '41	448	500	54 (12.1)	31 (6.2)	3 (0.7)	1 (0.2)	.....	.....
	Brown '42	250	250	16 (6.4)	18 (7.2)	1 (0.4)	.....	.....	.....
Dowagiac Creek	Rainbow '42	250	250	28 (11.2)	3 (1.2)	1 (0.4)	.....	.....	.....
	Brown '42	50	50	2 (4.0)	.....	1 (2.0)	.....	1 (1.0)	.....
Middle Branch, Ontonagon	Rainbow '42	150	150	11 (7.3)	3 (2.0)	.....	.....	.....	.....
	Brook '42	150	150	17 (11.3)	12 (8.0)	.....	.....	.....	.....
Kinne Creek[1]	Brown '39	994	.....	98 (9.6)	.....	10 (1.0)	.....	1 (0.1)	.....
	Brown '41	201	.....	56 (27.8)	.....	5 (2.5)	.....	.....	.....
	Rainbow '40	250	.....	85 (34.0)	.....	1 (0.4)	.....	.....	.....
	Rainbow '41	203	.....	77 (37.9)	.....	5 (2.5)	.....	.....	.....
	Brook '41	100	.....	23 (23.0)	.....	2 (2.0)	.....	1 (1.0)	.....
All plantings	Rainbow	2,352	1,869	429 (18.2)	132 (7.1)	14 (0.6)	3 (0.1)	.....	.....
	Brown	2,693	1,550	334 (12.4)	107 (6.9)	23 (0.9)	4 (0.3)	3 (0.1)	2 (0.1)
	Brook	250	150	40 (16.0)	12 (8.0)	2 (0.8)	.....	1 (0.4)	.....
	All species	5,295	3,569	803 (15.2)	251 (7.0)	39 (0.7)	6 (0.2)	4 (0.1–)	2 (0.1–)

[1]No fall plantings were made in this stream.

experiments conducted on public waters, where the percentages during the second season after planting have varied between 0.0 and 1.6 per cent (the 2.0 per cent recovery on the 1942 planting of brown trout in Dowagiac Creek in 1943 is not considered very significant, since only 50 fish were "available" and only one was recovered). This lower percentage of recovery during the second season after planting on public waters is probably due in part to more intensive angling.

Excluding the data from Kinne Creek (because there were no fall plantings in that stream), it appears that there is more than twice the chance of survival to the second and third seasons for spring-planted fish as there is for fall-planted fish (18 recoveries in the second and third seasons for spring-planted fish, 8 recoveries for fall-planted fish). There was some indication that boat planting possibly might have been a factor in the survival to the second and third seasons, as 16 of those reaching the second and third seasons were from boat plantings, while only 10 recoveries came from spot plantings.

Apparently very few hatchery-reared trout survive to reach the third open season after planting. Of marked hatchery fish planted since the spring of 1939 (approximately 10,000) we have records of only seven recoveries which were made during the third season after release. Five of these fish were brown trout and two were brook trout. Two of the brown trout came from a fall planting in 1940 in the Main Au Sable River, and another from a spring planting in Kinne Creek in 1939, while two brown trout from the 1942 spring releases in Dowagiac Creek and the Main Au Sable have been reported in 1944. Both of the brook trout were recovered from spring plantings —one from a release in Kinne Creek in 1941, the other from a planting on the Pine River in 1939 (not shown on Table 2). It would appear from the data at hand that there is more chance for season-to-season survival of spring-planted trout than for trout placed in the streams in the fall of the year, although the percentage of survival will vary with the species of trout, and from stream to stream. Among the three species season-to-season survival appears to be best among brown trout.

Comparison of Results of "Spot" Plantings and "Boat" (Scatter) Plantings

At each season of planting approximately one-half of each species of trout was released at a single spot, while the other half was distributed by boat above and below the locality of the "spot" planting. The fish released from the boat were scattered over from 1 to 3 miles of stream above and below a road bridge or landing.

The sorting of the 1942 recoveries as to whether they originated from "spot" plantings or "boat" plantings yielded no conclusive information. On some streams, and in some seasons, and for certain species, higher percentages of recovery were noted for "boat" plantings and in other situations the reverse was true (Table 3).

TABLE 3.—*Comparison of results from "spot" planting and "boat" plantings of legal trout, 1942 trout season, on Michigan trout streams*

[Figures in parentheses show number of anglers reporting indicated numbers of fish]

Stream	Number of recaptures reported from spring release						Number of recapture reported from fall release					
	Rainbow trout		Brown trout		Brook trout		Rainbow trout		Brown trout		Brook trout	
	Boat	Spot	Boat	Spot	Boat	Spot	Boat	Spot	Boat	Spot	Boat	Spot
Main Au Sable	32 (24)	19 (17)	16 (9)	16 (13)	....	....	16 (14)	7 (5)	8 (6)	10 (8)	....	....
Baldwin Creek	15 (13)	13 (13)	3 (3)	13 (9)	....	....	6 (6)	8 (7)	8 (6)	10 (8)	....	....
Dowagiac Creek	10 (9)	18 (14)	2 (2)	[1]....	....	....	3 (2)	[1]....	[1]....	[1]....	....	....
Portage Creek	....	17 (13)	....	3 (3)	....	....	....	2 (2)	....	[1]....	....	....
West Branch Sturgeon	....	....	....	....	9 (8)	9 (9)	....	....	....	....	1 (1)	3 (3)
Middle Branch Ontonagon	8 (8)	3 (3)	....	....	6 (6)	11 (6)	2 (2)	1 (1)	....	....	6 (6)	6 (6)
Totals	65 (54)	70 (60)	21 (14)	32 (25)	15 (14)	20 (15)	27 (24)	18 (15)	16 (14)	20 (16)	7 (7)	9 (9)
Total planted	450	550	275	300	325	325	450	550	275	300	325	325
Percentage recovered	14.4	12.7	7.0	10.7	4.6	6.1	6.0	3.2	5.8	6.6	2.1	2.8
Marked fish caught per angler reporting..	1.4	1.1	1.5	1.3	1.1	1.3	1.1	1.2	1.1	1.3	1.0	1.0+

[1]No fish caught from plantings. Other blanks indicate no plantings.

Theoretically, the fish distributed by boat should have been somewhat more difficult to recover, since they were spread originally over a much greater area of stream than were the "spot-planted" fish. The logical expectation is that a small number of anglers could remove a large number of hatchery trout that were planted by the "spot" method if the fish chose to remain "schooled up" at the point of planting. However, the 1942 data indicate a slightly higher catch per angler from spring stocking of "boat-planting" brown and rainbow trout. Furthermore, a slightly lower catch per angler was reported for recoveries from "boat-planted" brook trout. From the fall releases of 1941, "boat-planted" brown trout and rainbow trout yielded 0.1 fewer fish per angler reporting than did "spot" planting, and the yield per angler reporting marked brook trout was the same for the "spot" and the "boat" methods.

One phase of the problem of planting adult trout in streams which has not received a thorough test is a comparison of the results from "spot" and "boat" plantings made *during the open trout season.* It will be necessary in the future for the hatchery supervisors to know how widely the available stock must be dispersed over a stream during the open season so that the maximum number of fishermen can be benefited. Experiments on this phase of the problem will be conducted as soon as personnel is available.

Movements of the Planted Trout

The information available on the movements of the hatchery-reared trout of legal size after release in the fall of 1941 or the spring of 1942 is presented in Table 4. Not all recoveries were usable because of insufficient data on locality. The table shows the season, method of planting, the number of fish returned with sufficient locality data from each planting, and the distribution of these recoveries. The 1942 returns are summarized by species and season of planting, and the percentages of fish which were retaken at various distances from the release point are given. For purposes of comparison, similar data compiled from previous work on Michigan trout streams (Shetter and Hazzard, 1942) are included at the bottom of the table.

In studying this table the reader should remember that no effort has been made to offset possible inequalities in angling pressures on the various sections of stream areas listed in the table. To obtain a more accurate picture of the migrational tendencies of these fish, it would be necessary to know how many units of fishing effort were expended in the area of planting, and both above and below the area of planting.

Furthermore, any boat-planted trout recovered within the limits of the planted area was considered not to have moved. It was not practical to make a list of 250 or 125 planting locations and tag numbers while distributing fish from a rapidly drifting boat. It is likely that

TABLE 4.—*Numbers and percentages of fall- and spring-planted trout of legal size recovered at various distances and directions from points of planting in nine Michigan trout streams*

[Percentages are given in parentheses.]

Year of recovery	Species of trout	Season and year of planting	Method of planting	Recoveries with locality data	Number of fish moving			
					Upstream		Downstream	
					3-10 miles	3-0-3 miles	3-10 miles	over 10 miles
1942	Brook	Spring, '42	Boat	14	3 (21.4)	7 (50.0)	4 (28.6)	.....
			Spot	19	1 (5.4)	15 (78.9)	3 (15.7)	.....
		Fall, '41	Boat	7	1 (14.3)	4 (57.1)	2 (28.6)	.....
			Spot	9	.....	6 (66.7)	2 (22.2)	1 (11.1)
		All plantings combined		49	5 (10.2)	32 (65.4)	11 (22.4)	1 (2.0)
1942	Brown	Spring, '42	Boat	16	.....	16 (100.0)	.....	.....
			Spot	26	.....	22 (84.6)	3 (11.5)	1 (3.9)
		Fall, '41	Boat	13	.....	11 (84.6)	.....	2 (15.4)
			Spot	16	1 (6.2)	14 (87.5)	.....	1 (6.3)
		All plantings combined		71	1 (1.4)	63 (88.8)	3 (4.2)	4 (5.6)
1942	Rainbow	Spring, '42	Boat	57	.....	39 (68.5)	10 (17.5)	8 (14.0)
			Spot	62	2 (3.2)	44 (71.0)	8 (12.9)	8 (12.9)
		Fall, '41	Boat	23	1 (4.3)	17 (73.9)	4 (17.5)	1 (4.3)
			Spot	17	1 (15.9)	14 (82.3)	1 (5.9)	1 (5.9)
		All plantings combined		159	4 (2.5)	114 (71.7)	23 (14.5)	18 (11.3)
Totals, 1942	Brook	Spring, '42	Both	33	4 (12.1)	22 (66.7)	7 (21.2)	.....
		Fall, '41		16	1 (12.5)	10 (62.5)	4 (25.0)	1 (12.5)
	Brown	Spring, '42	Both	42	.....	38 (90.5)	3 (7.1)	1 (2.4)
		Fall, '41		29	1 (3.5)	25 (86.2)	.....	3 (10.3)
	Rainbow	Spring, '42	Both	119	2 (1.7)	83 (69.8)	18 (15.1)	16 (13.4)
		Fall, '41		40	2 (5.0)	31 (77.5)	5 (12.5)	2 (5.0)
1938, 1939, and 1941[1]	Brook	Spring	Both	908	104 (11.4)	385 (42.3)	407 (45.0)	12 (1.3)
		Fall		152	21 (15.0)	69 (45.3)	57 (37.6)	5 (3.0)
	Brown	Spring	Both	122	2 (2.0)	113 (92.0)	7 (6.0)	.....
		Fall		53	2 (4.1)	49 (91.8)	2 (4.1)	.....
	Rainbow	Spring	Both	356	.....	220 (61.7)	93 (26.3)	43 (12.0)
		Fall		61	2 (3.8)	44 (71.7)	13 (21.7)	2 (3.8)

[1]Results from Shetter and Hazzard (1942).

an unknown number of boat-planted fish actually may have moved anywhere from ½ to 3 miles farther than listed in the tables, as their movement up- or downstream, if recovered outside the planting area, was measured arbitrarily from the point of recovery to the nearest end of the stream section covered by the planting boat.

For all species and for both seasons of planting combined, it can be stated that 85 per cent or more of the fish recovered in 1942 (for which adequate locality data are available) were captured within 10 miles of the point or area of release. The average distance moved by fall-planted trout was slightly greater for brook trout and brown trout but less for rainbow trout than by fish of the same species planted in the same stream areas in the spring of the year. Apparently, then, fall release resulted in little or no advantage in securing a wider distribution over the stream area.

Among the planted brook trout, recovered in 1942, there was a tendency for about 20 to 25 per cent of the fish to move from 3 to 10 miles downstream, regardless of the time or method of planting. In the combined data for 3 years this percentage was even higher. The great majority of the remainder was captured within 3 miles of the planting locality (see Table 4).

From the data on movements of brown trout, one can conclude that approximately 85 to 90 per cent of the fish in any planting will be caught within 3 miles of the locality of release, and that of the remainder, the majority will be captured from 3 to 10 miles downstream from the planting area. Brown trout will travel considerable distances occasionally, however. For example one tagged brown trout released in the Main Au Sable near Grayling was recovered later 29 miles away by stream in the mid-course of the South Branch of the Au Sable (15 miles down the Main Au Sable, 14 miles up the South Branch).

The rainbow trout consistently disperses itself over a greater area than the other species if it has opportunity to do so. It can be observed in the table, however, that roughly from 60 to 80 per cent of the planted fish are taken within 3 miles of the point of planting. When this species does migrate, it usually travels farther than the others, sometimes going to the Great Lakes, and often to the lower sections of the streams. This tendency is reflected in the higher percentage of fish moving 10 or more miles.

The information available on the relative merits of "spot" and "boat" planting suggests that neither method has any great advantage over the other when pre-season plantings are made either in the spring or fall. Therefore, according to our data on the movements of planted trout, the best method of stocking a stream with "keeper" trout would be to make "spot" releases of moderate numbers of fish at approximately 3-mile intervals.

Results from Plantings in Trout Lakes

The results from experimental plantings of adult hatchery-reared brook trout in the fall of 1940 and of 1941 in suitable lakes in general paralleled the findings of Shetter and Hazzard (1942) with regard to rainbow trout of legal size planted in lakes in the fall. A tabular summary of information for the lakes on which creel-census data (taken during the 1941 and 1942 trout season) are available is presented in Table 5. Information from six fall plantings indicate that in lakes where conditions are favorable for brook trout, anywhere from 13.9 per cent to 88.1 per cent will be recovered by the anglers (average, 56.7 per cent) in the season following the fall of release. Individual weights and lengths of fish caught and observations of the census takers showed that the fall-planted trout made considerable growth over winter and that they were generally in good condition.

Table 5.—*Recovery of legal-sized brook trout in Michigan lakes during the trout season of 1941 and 1942 from plantings made in the preceding fall*

Lake	Number planted	Number recovered	Percentage of recovery	Total marked trout captured opening day	Percentage of total recovery on opening day
South Twin Lake[1]....	590	427	72.3	340	79.6
North Twin Lake[1]....	456	402	88.1	368	91.5
Holland Lake[2].....	200	136	68.0	129	.....
Kimes Lake[2].....	1,000	422	42.2	422	.....
East Fish Lake 1941	243	34	13.9	32	94.1
East Fish Lake 1942	250	133	53.5	123	92.4

[1]To July 1 only. An unmarked midseason planting interfered with further calculations.
[2]Creel census for first two days of 1942.
[3]Creel census records for opening day only, 1942.

Spring plantings of adult brook trout in lakes gave even higher percentages of recovery to the fishermen. Two releases of marked fish in the spring in East Fish Lake (Montmorency County) gave an average recovery of 68.5 per cent (57.4 per cent in 1941, 79.5 per cent in 1942) from plantings of 247 and 249 fish in the 2 years, respectively. Comparable numbers of adult fish released in the falls of 1940 and 1941 were recovered by angling in the following seasons at rates of 13.9 and 53.5 per cent—or an average recovery on the fall plantings of 33.8 per cent.

The data obtained in previous years concerning the success of plantings of rainbow trout in lakes, and the results from plantings of brook trout discussed above, demonstrate that very high percentages of adult fish planted in trout lakes in the fall of the year are available to and are taken by anglers in the season following release. The one unfavorable result of such a planting program has been from 80 to 94 per cent (average 89.4 per cent for the lakes under complete creel census) of the total trout catch for the whole season were taken on the opening day on lakes where adult brook trout were stocked

in the fall of 1941. Results of a comparable nature were noted in lakes of the Pigeon River Forest which were stocked with legal-sized rainbow trout (unpublished data). As far as these small "made" trout lakes are concerned, a small percentage of the total anglers using the lakes takes the majority of the fish planted in them.

Findings of Other Investigators

At this point it is of interest to summarize the results published by authors who have investigated the problems connected with the stocking of legal and near-legal trout. Since the work of Cobb (1934) in Connecticut, a number of studies pertinent to this problem have been carried out in widely scattered sections of the United States and reported in various publications. For the convenience of the reader, the salient information secured in these experiments is recorded in Table 6, in such a form that a comparison of results can be made with greater ease. The table includes the following items: Author; publication date; state or area in which experiments were conducted; species of trout; size of fish; number of plantings; percentage of recovery from spring, fall, and open season plantings; the type of mark used; and the method of recovery.

Several investigators have conducted experiments involving the planting of marked trout of legal size during the open season. For brook trout, the experiments of Cobb (1934), Hoover, and Johnson (1937), Hazzard and Shetter (1939), and King (1942) demonstrated a very rapid rate of removal within 1 to 4 weeks. Percentages of recovery varied from 5.0 in Minnesota (Smith and Smith, 1946) to 76.0 in New Hampshire (Hoover and Johnson, 1938). The Minnesota figure is the only one below 25 per cent, and it is possible the low recovery on that particular group of summer-planted brook trout was the result of a severe flood shortly after the release.

Legal-sized brown trout were marked and released during the open season by Cobb (1934), Hazzard and Shetter (1942), and Smith and Smith (1945). Lower percentages of recovery (varying from 9.6 to 33.0 per cent) than with brook trout and rainbow trout were recorded for such plantings. The above-mentioned authors all noted that the hatchery-reared brown trout were not removed by angling as rapidly as were brook trout or rainbow trout.

Legal-sized rainbow trout planted during the course of the angling season appear to have an excellent chance of recovery by anglers. Percentages of recovery in Michigan, Tennessee, and New Mexico (in the latter State on the native Rio Grande cutthroat trout, *Salmo clarkii spilurus*) ran from 25.7 to 67.1 (Shetter and Hazzard, 1942; Gee, 1940 and 1942; King, 1942). Hatchery rainbow trout usually entered the catch in fair numbers up to 8 weeks after release, except in Gee's experiments in the Southwest, where the majority of the marked hatchery fish recaptured often were taken out within 3 weeks.

TABLE 6.—*Percentages of recovery obtained by anglers from plantings of legal- and near-legal-sized trout in streams at various seasons of the year in various states*

Author and publication date	State or area	Species of trout	Number of plantings	Total length of fish (in inches where given)	Percentage of recovery by anglers of plantings			Type of mark used	Method of collecting data
					Spring	Fall	Open season		
Cobb, 1934	Connecticut	Brook, Brown	Several	Legal	.....	.....	33	Belly-tag	Lottery
Hoover and Johnson, 1938	New Hampshire	Brook	1	Legal	.....	.....	76	Gill-cover tag[3]	Creel census
Nesbit and Kitson, 1937	Massachusetts	Brown	4	8-9	9.1 11.7	3.1 2.3	.....	Internal tag	Voluntary
		Rainbow	2	7½-8	14.9	1.5	.....		do
Lord, 1936	Vermont	Rainbow	1	6-12	.....	27.9	.....	Fin-clip	do
Shetter and Hazzard, 1942	Michigan	Brook	18	7-13	25.5[1]	4.4[1]	25.4[1]	Jaw-tag and fin-clip	Creel census
		Brown	10	7-13	11.3[1]	5.8[1]	13.0[1]		do
		Rainbow	18	7-13	19.6[1]	4.9[1]	25.7[1]		do
Smith, 1941	Michigan	Brook	5	7-9	18.0	0.5[1]	.....	Jaw-tag	do
Smith and Smith, 1945	Minnesota	Brook	4	7-10	26.2 19.6	2.4	5.0	Jaw-tag	do
		Brown	5	7-10	28.0 8.6	21.7 1.4	9.6		
Schneberger and Williamson, 1943..	Wisconsin	Brook	2	7-13	82.0	28.2	.....	Fin-clip	Incomplete creel census
		Rainbow	2	7-15	30.5	48.4	.....	Fin-clip	
Chamberlain, 1943..	Pisgah National Forest	Brook	14	5-9	58.8[1]	6.4[1]	.....	Fin-clip	Creel census
		Brown	6	5-9	15.6[1]	14.3[1]	.....	Fin-clip	do
		Rainbow	14	5-9	44.5[1]	9.2[1]	.....	Fin-clip	do
King, 1942	Great Smoky Mountain National Park	Brook	2	Legal	50	.....	64.6	Fin-clip[4]	do
		Rainbow	2	Legal	?	.....	67.1	Fin-clip	do
Gee, 1940	New Mexico	Rainbow	1	8	58.8	.....	.....	Tag	do
Gee, 1942	New Mexico	Rainbow	6	6-9	28.2-72.0[2]	2.2	.....	Jaw-tag	do
		Cutthroat	3	6-11	.....	7.7	47.4[1]	Jaw-tag	do
		Wild cutthroat	2	6-9	42.6[1]	.....	.....	Jaw-tag	do
Trembley, 1945	Pennsylvania	Brook	2	Legal	55.8	47.0	.....	Jaw-tag	do[5]
		Brown	2	Legal	46.7	56.4	.....	Jaw-tag	do[5]
		Rainbow	2	Legal	60.0	46.4	.....	Jaw-tag	do[5]
Hescox, 1944	New York	Brown	10	Legal and sublegal	3.07-5.91[2]	7.38-8.73[2]	.....	Fin-clip	Random creel census

[1]Average percentage of recovery from two or more experiments.
[2]Range in percentage of recovery from several experiments.
[3]Self-locking paper clip.
[4]Spring planting marked by punching hole in caudal; mark unsatisfactory on rainbow trout.
[5]Only marked fish recorded.

The results of experiments by various individuals concerning the comparative efficiency of fall and spring plantings of brook trout in streams can be summarized as follows. Six investigators in five different states (see Table 6) found spring planting of legal-sized brook trout to be superior to fall planting by margins varying from about 20 to 2,000 per cent. In Spring Creek, Pennsylvania, Trembley (1945) determined that percentages of recovery from fall plantings compared favorably with those obtained from spring planting, and inferred that winter conditions were extremely favorable in that particular stream because of the large amount of spring water present. It should be pointed out, however, that a measurably greater percentage of spring-planted brook trout were taken than of fall-planted brook trout even in Trembley's study.

The stocking of legal-sized rainbow trout in streams in the spring has, according to most records, proven to be a far sounder management procedure than fall stocking of this particular species. In Massachusetts, New Mexico, North Carolina, and Michigan, recoveries of marked fish from spring plantings outnumbered recoveries from fall plantings by a ratio of from 5 to 36:1. Only in Wisconsin and Pennsylvania were the results radically different. Schneberger and Williamson (1943) obtained recoveries of 30.5 per cent on a spring planting and 48.4 per cent on a fall planting of rainbow trout in the Deerskin River in Wisconsin. They remarked, however, that numerous survivors from the fall stocking were in poor condition and were left at the streamside by the anglers. Trembley (1945) recorded a recovery of 60.0 per cent for spring-planted, legal-sized rainbow trout as against a 46.4 per cent recovery for the fall-planted fish from Spring Creek, Pennsylvania—an excellent recovery for the fall planting, yet still about one-fourth less than for those released in the spring of the year. Lord (1936) reported a recovery of 27.9 per cent from a fall planting of rainbow trout in a Vermont stream, but gave no comparable data for spring planting.

As will be noted from an inspection of Table 6, the results from the plantings of legal-sized brown trout in the spring and fall are somewhat at variance with those for other species. In Massachusetts, Nesbit and Kitson (1937) found that fall plantings of this species were inferior to spring plantings by a ratio of about 3:1. In Michigan the comparison was found to be 2:1 in favor of spring planting in one set of experiments, and 1.4:1 in another. Chamberlain (1943), in his extensive work in the Pisgah National Forest found the ratio to be about 1:1 for spring and fall plantings of legal brown trout. Trembley (1945) secured the best results, as far as fall planting is concerned, from legal brown trout in Spring Creek in Pennsylvania. Here the ratio of recoveries of fall-planted fish to those of spring-planted fish in the anglers' catch was found to be slightly more than 1.2 to 1.

In one stream (Knife River) in the Lake Superior drainage of Minnesota, Smith and Smith (1945) found that fall plantings of tagged adult brown trout were recovered at a rate of 1.4 per cent, while marked fish planted in the spring were recaptured at a rate of 8.6 per cent. In a southeastern Minnesota stream (Duschee Creek) tagged brown trout released in the fall were recovered in the following season at the rate of 21.7 per cent, and spring plantings of similar numbers of tagged brown trout were recaptured at the rate of 28.0 per cent. The authors ascribed the excellent showing of the fall planting in Duschee Creek to an abundant supply of spring water which kept the stream open during most of the winter (*cf* Trembley, 1945).

From marking experiments on brown trout conducted in connection with a random creel census on the East Koy and Wiscoy Creeks in New York, Heacox (1944) reported the following results: for fall planting, a recovery of 7.35 to 8.73 per cent; for spring planting, a recovery of 1.19 to 5.81 per cent. Heacox also mentioned that in both seasons in which the creel census was conducted that the most recently planted fish were not the first to be removed by angling.

It should be mentioned that not all of the experiments summarized in Table 6 were conducted in a similar manner. The reader who studies the various reports listed will note that in certain of the experiments more fish were planted in the spring, or more in the fall, or that the fish planted at one season were of a much greater average size than those planted at another season. Differences in size frequently can be attributed to the fact that fish of the same stock will average slightly larger in the spring of the year than during the preceding fall. It is the author's belief, however, that equal numbers of fish of approximately the same size planted at the various seasons will give the most reliable comparison of recovery percentages. It has been noted for example (Hazzard and Shetter, 1941; Gee, 1942) that smaller plantings often will yield higher percentages of recovery to the anglers than will larger plantings. It is not impossible that the size of the planting influenced the results of Trembley in Pennsylvania and of Heacox in New York where unequal numbers of fish were stocked in the spring and fall. In the New York experiments from two to four times as many marked fish were released in the spring as in the fall, while in Pennsylvania considerably more marked fish were planted in the fall than in the spring.

The work of Kelez (1937), although conducted on coho salmon fingerlings, suggests that size at time of release may be an important factor in the survival to maturity. He released two lots of marked coho fingerlings from the same hatch. One lot measured 1⅞ inches (average length) in May 1934; the other averaged 4 inches in November 1934. The proportion of large fish to small fish later recovered as adults was 65 to 1. Since the trouts and salmons are closely related, it is not unreasonable to hold that percentages of recovery might be

affected by a great variation in average size between a group of trout planted in the fall and other group released in the spring.

Another factor that may affect the validity of the comparison of results recorded by different workers has been the variation in the legal size for trout in the states where the experiments were conducted. According to a summary published by *Outdoor Life* in April 1938, two of the states (California, Minnesota) had no legal length; seven states (New Mexico, North Carolina, Pennsylvania, Connecticut, Massachusetts, New Hampshire, and Vermont) had a 6-inch size limit, while five states (Michigan, Wisconsin, New York, Tennessee, and Arizona) required anglers to release trout under 7 inches. In North Carolina, rainbow trout and brown trout were protected up to a size of 8 inches, but brook trout were legal at 6 inches. Some variation in percentages of recovery might be expected between trout planted at sizes of 6, 7, and 8 inches.

Although comparatively poor results (in terms of fish later creeled by the angler) have been noted from fall plantings in streams, good to excellent percentages of survival have been recorded when legal-sized trout have been released in lakes where conditions are favorable for their establishment. Table 7 presents a brief summary of results obtained by seven investigators in four different localities. Very good recoveries (27.0 to 56.7 per cent) have been observed for adult brook trout and rainbow trout planted in lakes in the fall of the year. It was noted in East Fish Lake in Michigan that the survival to the creel was higher for spring-planted brook than for fall-planted fish—even though the survival of the fall-planted fish was good. Whether or not spring plantings would give yields any higher than those listed for certain of the fall plantings in Table 7 will have to be determined by further experimentation. If the cost of carrying such fish in hatchery ponds over the winter is excessive, then the lakes should be stocked in the fall.

In the only experiment which involved the release of brown trout in ponds, Nesbit and Kitson (1937) found that spring releases yielded twice as many fish to the angler as fall plantings.

The release of brook trout and rainbow trout in lakes during the open season in Michigan and California gave yields varying from 17.3 to 52.6 per cent of the number planted.

Possible Causes of Mortality among Fall-planted Adult Trout in Streams

The higher survival to the creel of spring and open-season plantings of legal-sized fish released in streams has not been explained by any worker, as yet. Some possible contributing factors are discussed in the following paragraphs.

The variation in results obtained from plantings in lakes and streams suggests that the environment for trout in winter is not as

TABLE 7.—*Percentages of recovery obtained by anglers from plantings of legal- and near-legal-sized trout in lakes and ponds at various seasons of the year in various localities*

Author and publication date	State	Species of trout	Number of plantings	Total length of fish (inches)	Percentage of recovery by anglers of plantings			Type of mark	Method of collecting data
					Spring	Fall	Open season		
Nesbit and Kitson, 1937	Massachusetts	Brown	2	9.0, 8.3	2 2	1.1	.....	Belly tag	Voluntary
		Rainbow	2	7.8, 8.0	9.2	4.3	.....	Belly tag	
Shetter and Hazzard, 1941	Michigan	Rainbow	6	7-14	.....	27.0[1]	48.0[1]	Tag and fin-clip	Creel census and voluntary
Shetter, present study	Michigan	Brook	8	7-10	68.5[1 5]	56.7[1]	.....	Tag and fin-clip	Partial and complete creel census
Needham, 1937	California	Rainbow	1	4.7	.....	.....	17.3	Fin-clip	Creel census
Needham and Sumner, 1942	California	Brook	1	5.5	.....	.....	22.7	Fin-clip	Creel census
Vestal, 1943	California	Rainbow	4	4.6	.....	.....	18.2-52.6[2 3]	Fin-clip	Incomplete creel census
Keil, 1938	New York	Rainbow and ouananiche[4]	5	8-10	.....	50.0[1]	.....	Not marked	Creel census

[1]Average percentage of recovery from several experiments.
[2]Range in percentages of recovery from several experiments.
[3]Estimated from a sample of the catch taken at one boat landing on June Lake.
[4]*Salmo salar sebago.*
[5]Data from Institute for Fisheries Research Report No. 848 (unpublished).

favorable in streams as in lakes. From this one might infer that if streams contained more deep, quiet pools (approaching lake conditions), survival of fall plantings to the following spring would be better.

So far as is known, cannibalism is not an important factor in the survival of legal-sized trout. Although many of the lakes contained some large trout when the experimental plantings were made, the percentage of survival of fall plantings in lakes has been much higher than in streams.

Trout resident in streams probably are subject to a larger amount of predation by birds and mammals in winter than are those which live in lakes, since most lakes are deeper and will freeze over. In severe winters, stream-inhabiting mergansers are known to account for a part of the over-winter losses, and in some localities mink and otter may cause some loss.

Competition for available food and space apparently is an important factor in determining the success of a fall planting. In Michigan, creel censuses indicate that the majority of streams studied to date have moderately large populations of naturally-spawned trout, as proved by the relatively low percentage of the total catch made up of marked hatchery fish. In these same streams, recovery percentages on fall plantings of trout have been low (Shetter and Hazzard, 1941). In certain streams of New York (Heacox, 1944), Pennsylvania (Trembley, 1945), and North Carolina (Chamberlain, 1943) creel-census or other reports indicate that the native trout populations are small, since 80 or more per cent of the total catch has been observed to consist of marked hatchery-reared trout. These same streams are among those reported to furnish a good survival of fall-planted fish. The lack of competition from naturally-reared fish may be the explanation for the much better survival of fall plantings in some localities.

The effect of floods caused by cloudbursts or sudden spring thaws should be given more consideration as a factor in the reduction of the number of catchable trout. That a flood caused by a cloudburst can eliminate entirely a fall planting of brook trout has been recorded by Chamberlain (1943). Further evidence on the severe effect of floods was given by Smith and Smith (1945). The percentages of recovery on open-season plantings of tagged brook trout and brown trout in Duschee Creek, Minnesota, were 5.0 and 9.6 respectively. The authors stated that the plantings were followed by a heavy flood. The unsuitable conditions brought about as a result of the high water probably accounted for the comparatively low percentages of recovery from this open-season planting. Fall plantings would be more likely to be affected by floods than other plantings because of the relationship between the time of release, the usual time of flood, and the opening of the fishing season. It is not impossible that many trout from releases

made at any season are lost when flash floods occur and carry fish from good trout habits into the lower reaches of streams where temperatures or other conditions are not suitable, or where a large population of predacious fish resides.

In all probability, all the factors just mentioned contribute to the decimation of an autumn release. The net result is usually a comparatively small number of legal fish remaining for the angler. The spring and open-season plantings have been more successful probably because there was less time for natural catastrophes to operate on the fish before they were subjected to angling.

Conclusions

From an analysis of the results of marking experiments conducted in Michigan and in numerous other localities throughout the United States to determine the proper season at which to release trout of legal size, the following conclusions appear to be warranted:

1. In the planting of brook trout and rainbow trout, 6 inches or more long, in streams significantly larger percentages of survival to the creel have been noted in the majority of experiments for spring and open-season plantings. Where fall plantings of these species have shown returns almost as good as spring plantings (Pennsylvania), the investigator ascribed the better-than-average survival of the fall plantings to an abundant supply of spring water which ameliorated normal winter conditions in the streams in question.

2. It is suggested by the experiments involving brown trout of legal size, both in Michigan and elsewhere, that this species, when planted in streams, seems to survive winter conditions better than do brook trout and rainbow trout. In some localities fall plantings of brown trout apparently yield as many or more fish to the angler as spring plantings of similar numbers of fish. The localities where fall plantings gave as good or better results than spring releases, had either an excellent spring-water supply (Spring Creek, Pennsylvania; Duschee Creek, Minnesota) or a very low population of native trout (East Koy and Wiscoy Creeks, New York; South Mills Creek, North Carolina). In the Michigan experiments with brown trout, from 1½ to 2 spring-planted fish were recovered for every fall-planted fish. It is of interest to note that the percentage of recovery of plantings of brown trout at any season were the lowest for any of the three species.

3. The carry-over to subsequent seasons following the first season of availability (although always small) was noted to be the greater of spring-planted fish in Michigan, Pennsylvania, and New York, despite the variation in results during the first season of availability. The fact that fall plantings showed the higher percentage of carry-over past the first season of availability in Chamberlain's experiments in North Carolina possibly was a result of the former Forest Service

policy of closing several of the experimental streams for 1 or 2 years in every 5.

4. As far as can be determined from the data at hand, neither "spot" nor "boat" planting has demonstrated any great superiority over the other in releases made in the fall or in the spring before the season opens. The relative merits of the two methods should be tested on plantings of "keeper" trout in streams during the open season.

5. In Michigan trout streams, the 1942 data indicated that 85 per cent or more of the planted trout that were recaptured were taken within 10 miles of the locality of release, and that from 45 to 90 per cent were taken within 3 miles of the point of release. Brook trout planted either in the spring or the fall had a slight tendency to move downstream from 3 to 10 miles. A greater percentage of rainbow trout than of other species tended to move over 10 miles in a downstream direction. Brown trout were the least migratory of any of the fish during the 1942 work.

6. Results from creel censuses and marking experiments on lakes suitable for trout in Michigan and elsewhere have proven that from 13 to 88 per cent of fall-planted brook trout and rainbow trout will be removed by angling in following seasons—a much better return to the angler than has been found for fall plantings in streams. The worst feature of such a management program, at least in Michigan, is that an average of about 90 per cent of the season's catch on these trout lakes is removed during the first 2 weeks of the open season by a very small percentage of the total number of anglers who use the lake. This situation requires correction, either by lowering the creel limit on such water, or by special regulations, or other means.

7. The following possible explanations were advanced for the failure of fall plantings in streams to furnish good fishing in following seasons:

a. Lack of suitable habitat in streams in winter,
b. Predation by birds and mammals.
e. Competition between fall-planted trout and native trout for food and space,
d. Losses of unknown magnitude caused by floods.

8. It would appear that the proper time to plant legal-sized trout (especially in streams) has, in general, been demonstrated adequately to be in the spring or during the open season. The studies of various workers have proven too, that better returns to the angler come from releases of adult fish rather than fry or fingerlings. If it is assumed that planting legal-sized trout is a justifiable procedure, the questions to be answered in the future, if we are to utilize these legal trout to the highest degree are as follows:

a. Which streams and lakes are to be planted, and with what species?

b. What is the fishing pressure?

c. What is the approximate population of wild trout?

The first question has been, and is being answered by lake and stream surveys in a number of states.

The second question can be answered only by accurate creel-census studies, which are (or were before the war) pursued with vigor in numerous states and areas. A sampling technique is needed which is reasonably accurate, yet which is inexpensive in comparison with the intensive or "complete" type of creel census. It will be financially impossible to cover the major trout streams of any of the larger states by the present intensive creel-census methods. Some method of measuring angling pressure and total catch must be devised, however, if the danger of overstocking is to be avoided. The studies of Chamberlain (1943) on the Pisgah National Forest furnish an excellent example of how easily the carrying capacity of a stream may be misjudged.

The third question is a challenge to the field investigators. Some progress has been made in recent years through the development of the electric 'shocker" (Haskell, 1941) for use in studying populations of trout streams. The method of conducting population studies in lakes by netting and fin-clipping (Schnabel, 1938) is laborious and time-consuming. More rapid and accurate field techniques must be developed for both types of research.

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A SYSTEM FOR RECORDING MEASUREMENTS OF FISH SCALES

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ABSTRACT

A system for recording measurements of fish scales is described. Symbols to denote various features of life history and, in the case of doubtful features, to express the "degree of doubt" in a definite manner, are listed. Two alternative procedures for gauging the validity of scale interpretations are suggested.

In the course of measuring many thousands of trout and salmon scales, the writer has found the system described below to be useful in keeping a record of scale measurements. The system is applicable to fish which have made some growth in either fresh or salt water, or in a combination of the two. All measurements have been made along the anterior radius of the scale, using a microscope and a mechanical stage, with attached micrometer which recorded in hundredths of a millimeter. The general arrangement for recording measurements is the following:

Fish No.	Date	Sex	Fish length	First year	Second year	Third year	Fourth year	Intermediate	Remarks
				25	56	80	*245*	95	

Measurements in Roman type (black pencil in MS) denote freshwater or intermediate growth, and those in italics (red pencil in MS) denote salt-water growth. All measurements are cumulative. "Intermediate" growth is that made in fresh or brackish water during the season in which the fish migrated to sea, and includes growth made both in the stream and in the lagoon or estuary at the mouth of the stream. Thus, it represents only a part of a growing season. Measurements under the columns "First year," "Second year," etc., represent growth made through an entire growing season, including the annulus at the end of the season. If the fish population concerned occurs in fresh water or salt water alone or exhibits no intermediate growth, the arrangement is further simplified.

An "R" in place of or following an initial measurement denotes that the scale is regenerated to such an extent that it is impossible to determine whether or not one or more annuli are missing.

An "(R)" following an initial measurement denotes that the scale is a regenerated one, but that all of the annuli are believed to be present. In some such cases the measurement to the first annulus

may be affected, so that it is doubtful that such scales should be used in calculating growth.

A minus sign (—) following an "R" or "(R)" shows that no more scales are left in the scale book or scale enevelope.

An "A" following a final measurement denotes that an annulus is present at the edge of the scale.

A plus sign (+) following a final measurement indicates that spawning absorption may have been sufficient to affect the measurement. Such scales should not be used in calculating growth.

An "S" following a measurement denotes a spawning mark. The spawning mark may obliterate an annulus formed at about the same time. However, in a few cases the spawning mark may be separated from the annulus. In such cases the measurement is made to the spawning mark and not to the annulus, since the growing season proper follows spawning.

A false check (incidental check, accessory check) is denoted by the letters "FC" preceding a measurement, and the measurement is recorded in the column headed "Remarks."

In almost any series of scales, doubtful features will be encountered. In such cases it is highly desirable to express the "degree of doubt" in a definite manner, so that it will be known upon re-examination of the scales by the same or another investigator. A "?" following a measurement or symbol indicates that no decision could be reached regarding the validity of the feature indicated by the measurement or symbol. A "(?)" following a measurement or symbol denotes that the indicated feature was questionable, but was believed to be valid. Parentheses around *both* the measurement or symbol and the question mark denote that the indicated feature was questionable, but was believed to be not valid.

If measurements of more than one scale from the same sample are made, the measurements may be separated by a "/" sign under each column heading.

The various applications of the described system are illustrated on page 61.

The individual investigator may also wish to adopt certain additional symbols or columns. For example, the writer was dealing with both marked and unmarked fish, and so added a column headed "Marks." In addition, he wishes in the case of some scale samples to make supplementary notes, and so adopted a series of distinctive numbers and assigned corresponding numbers to the notes. He also wished to make note of scale samples with false spawning marks, and so inscribed the symbol FS after the measurements concerned. Underscoring of this symbol denoted that the false spawning mark was accompanied by erosion.

Two alternative procedures are suggested for gauging the validity of scale interpretations. (1) The investigator first records all measurements according to his best judgment, without distinguishing between

Fish No.	Date	Sex	Fish length	First year	Second year	Third year	Fourth year	Intermediate	Remarks
				38 (R)–	1828	2818	318+	64	FC 57
				39	83	324	448	106	
				32(1)	46	192		56	FC(1)65/72
				49/43	95/86	318/300	408/384		
					R–	319	406		
				40	82	115A			

"certain" and doubtful interpretations. He (or another investigator) then reexamines the entire series. Interpretations which check are then listed as certain, while those which do not check are listed as doubtful, in accordance with the system previously outlined. (2) The investigator first records all measurements and immediately denotes doubtful features. He (or another investigator) then reexamines the doubtful scales only. If a doubtful but probable feature is interpreted in the same way on each occasion, the interpretation is listed as "certain."

ANGLING EXPERIMENTS BY THE FLY TYERS CLUB AT CORNELL UNIVERSITY

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ABSTRACT

A joint experiment was conducted during the spring of 1942 by the Fly Tyers Club and the Laboratory of Limnology and Fisheries, Cornell University to determine the catch per unit effort from a known trout population and to test some angling theories. A 2,000-foot section of Cascadilla Creek, on the grounds of the University Experimental Fish Hatchery was closed off by weirs. Experience has shown that the natural trout population in this area is for practical purposes non existent. One hundred and fifty 8- to 13-inch rainbow trout (*Salmo gairdnerii*), mostly wild stock, were planted on April 16. Twenty trout were used as replacement for trout killed and in addition 30 marked trout were planted on May 11, increasing the theoretical population to 180 fish. Thus a total of 200 trout were involved in the experiment. Fishing pressure was supplied by seven members of the Fly Tyers Club and complete catch records were kept. The stream was fished on 54 days between April 17 and June 12 during which 307 hours were expended to catch 601 trout. Thus each trout was caught an average of 3 times and the seasonal catch per unit effort was about 2 trout per hour. When the fishing period is divided into nine 6-day periods no significant difference may be demonstrated in the catch per unit effort for the several periods. Although consistently good fishing was produced, all effort expended was not fruitful. About 20 per cent of the anglers caught no trout. A ratio of 1:5.5 was observed in the catch of marked and unmarked trout, which approximates the theoretical of 1:5. A marked downstream movement was noted among newly planted trout. Temperatures as high as 76° F. did not noticeably affect the interest of the trout in artificial lures. In a wet fly experiment five anglers fished five patterns on 5 days, the arrangement being distributed at random with the specification that each pattern be used once by each angler and once each day. Standardized terminal tackle was used and each lure was fished for 2 hours a day. A total of 112 trout was caught. When the data were analyzed by analysis of variance, no significant differences could be demonstrated for the various flies during the 5 day period; differences between anglers and between fishing days were highly significant. In a similar experiment involving the use of four dry flies (gray and black bi-visible type flies with clipped and unclipped hackles), a total of 91 trout were caught in the 4 days of fishing. No significant differences could be shown between flies, days or anglers. It appeared that the black flies were more effective than the light gray ones on dark overcast days.

Introduction

During the spring of 1942 a joint experiment was carried out by the Fly Tyers Club and the Laboratory of Limnology and Fisheries, Cornell University. The purpose of the experiment was to obtain data on the catch per unit of effort from known trout populations and to test some angling theories.

The experimental area consisted of a 2,000-foot section of Cascadilla Creek near the Cornell University Experimental Fish Hatchery. Movements of trout in or out of the area were barred by two lath weirs installed at the upper and lower extremities. This section of the stream is not considered trout water although a few brown trout are occasionally taken. The stream's high summer temperatures, low water, and food supply, made uncertain by seasonal flooding, preclude the possibility of supporting a large population of resident trout. During the spring, however, the water is quite habitable for trout. The experimental section presented an interesting variety of natural riffles and pools, as well as a Hewitt-type dam and two log barriers, which provided ample cover and fishing water during the experiment.

Two hundred rainbow trout (*Salmo gairdnerii*) were purchased from Mr. H. K. Annin of the Caledonia Trout Ponds, Caledonia, New York. These were mostly wild stock and ranged in length from eight to thirteen inches. Of this number, 150 were liberated on April 16, the day before the fishing began (rate of about 400 trout per mile). By May 11, 20 of the 50 fish in reserve had been used, and the remaining fish were marked by clipping the adipose fin and released. This brought the theoretical population in the area up to 180 trout.[1]

Fishing effort was supplied by seven participating members of the Fly Tyers Club and only artificial flies were used. Each angler was responsible for keeping records on (1) time of day fished, (2) patterns and types of lures used, (3) numbers of trout caught on each lure, and (4) appropriate notes on stream conditions or angling experiences. In addition to this routine information acquired from all fishing, two special experiments were designed to test the relative merits of certain flies, one on five patterns of wet flies and another on four types of dry flies.

The Season's Catch

The data summarizing the season's catch by days are presented in Table 1. The stream was fished a total of 54 days, during which 307 hours were expended to catch 601 rainbow trout. Thus the 200 trout were caught on an average of about three times each! In other

[1]In addition, the following large trout were planted from the Cornell Experimental Hatchery: 10 rainbow trout, 14 to 16 inches; 4 brown trout (*Salmo trutta*), 13 to 18 inches; and 3 brook trout (*Salvelinus fontinalis*), 12 inches. These were not included in any of the computations given in the text, but the total catch of these fish was as follows: 27 rainbow trout (caught an average of 2.7 times); 8 brown trout (average of 2.0 times); and 8 brook trout (average of 2.7 times).

words, 200 trout provided fishing that otherwise would have taken 600, had all the fish been removed as caught. Although the anglers had the privilege of removing some fish, only twenty trout were killed during the experiment, and some of these were taken only because they had been fatally hooked. The scope and application of the data are both limited and conditioned by the small amount of effort involved, but certain observations may be of value.

TABLE 1.—*Catch and effort data for 54 days of experimental fishing on Cascadilla Creek, 1942*

Date		Number of anglers	Hours	Catch of rainbow trout	Catch per hour
April	17	6	11.50	38	3.3
	18	5	4.50	19	4.2
	19	5	5.25	5	1.0
	20	5	4.25	4	0.9
	21	10	13.50	22	1.6
	22	8	14.25	17	1.2
	23	5	5.75	12	2.1
	24	8	11.00	17	1.5
	25	4	4.50	14	3.1
	26	6	12.50	22	1.8
	27	5	6.50	24	3.7
	28	15	15.50	24	1.5
	29	12	11.00	16	1.4
	30	14	14.50	25	1.7
May	1	1	0.50	0	0.0
	2	1	0.75	1	1.3
	3	1	1.00	2	2.0
	4	4	5.00	8	1.6
	5	1	1.25	1	0.8
	6	13	11.75	30	2.6
	7	14	14.50	9	0.6
	8	2	1.75	5	2.8
	9	1	1.75	9	5.1
	10	2	2.50	1	0.4
	11	5	5.25	19	3.6
	12	7	9.50	19	2.0
	13	11	9.75	36	3.7
	14	10	10.50	10	1.0
	15	8	8.00	16	2.0
	16	2	1.00	4	4.0
	17	11	13.00	25	1.9
	18	5	5.00	8	1.6
	19	1	0.25	1	4.0
	20	1	1.50	6	4.0
	21	2	2.00	0	0.0
	23	1	1.50	2	1.3
	24	3	6.50	15	2.3
	25	6	9.50	22	2.3
	26	2	4.00	2	0.5
	27	5	6.25	11	1.8
	28	3	3.75	16	4.3
	29	5	5.75	11	1.9
	30	3	3.75	2	0.5
June	1	1	1.00	1	1.0
	2	2	4.50	4	0.9
	3	3	4.50	16	3.6
	4	1	1.00	5	5.0
	6	3	3.25	5	1.5
	7	1	1.00	2	2.0
	8	3	2.50	9	3.6
	9	4	4.75	8	1.7
	10	1	1.00	0	0.0
	11	1	0.75	1	1.3
	12	1	1.00	0	0.0
Total		260	307.25	601	2.0

The average daily catch per hour during the period of April 17 through May 10, when the population was kept at 150 trout, was 1.9 trout. For the remaining fishing period, while temperature conditions were favorable (through June 6), the catch per hour was 2.3 trout, with a population of 180 trout. The increase may not be shown to be significant.

When the data are divided into nine six-day periods, no significant differences may be shown by analysis of variance among the several mean catches per unit effort stated in Table 2. Insofar as the data go, there was a rather uniform catch of about two trout per hour. Certainly continued fishing over these trout did not result in any apparent increased difficulty of capture.

TABLE 2.—*Average catch per hour of rainbow trout summarized by six-day periods, Cascadilla Creek, 1942*

Period	1	2	3	4	5	6	7	8	9
Trout per hour....	2.0	2.3	1.3	2.0	2.7	2.1	2 2	2.1	1.4

The data presented may be considered an example of consistently good and sustained fishing, in contrast to the rapid population depletion frequently experienced in heavily fished public waters. An inspection of individual catch records shows, however, that even in this situation it was not always possible to catch trout. The frequency of the number of trout caught by each angler, expressed as an approximate percentage of the total anglers (260) is given in Table 3. The distribution observed is decidedly skewed.

TABLE 3.—*Distribution of the number of trout creeled per angler, Cascadilla Creek, 1942*

[Expressed as a percentage of the total number of anglers]

Number of trout creeled	0	1	2	3	4	5	6	7	8	9	10	11	12
Percentage of anglers....	22	24	18	11	9	4	4	3	2	1	0	1	1

The theoretical relation of the marked trout planted on May 11 to the original population was 30:150 or 1:5. In the catch of trout after May 11, 41 marked trout were taken out of a total of 265 fish which were examined for the missing fin. The ratio of marked to unmarked trout was 1:5.5, thus approximating the theoretical. Proportionally, the population of unmarked trout could be computed as 164, an overestimation of about 10 percent.

There can be little doubt that the trout fared very poorly on the scant supply of natural food. It was quite apparent that the trout by late May had lost considerable weight and it is perhaps worthy to note, that although the trout were not getting enough food to maintain themselves, they did not take recklessly every artificial that was cast over them.

It was evident on the first day of fishing that there had been a marked movement downstream since planting on the day previous. Many fish were concentrated in the pool backed up by the weir.

This concentration was noted for about a week, after which the fish redistributed themselves. Trout were observed trying to get through the upper weir for only a few days beginning April 23.

The clipped rainbow trout released on May 11 were all planted in the middle section of the experimental area. Seven hours later four were taken about 200 feet above the lower weir. From the places where they were caught during the ensuing days, it was observed, as at the beginning of the experiment, that many more had moved down stream than upstream from where they had been planted. However, by the end of May the marked fish were being taken from waters throughout the entire experimental area.

At first the trout congregated in the deeper pools, but by late April many of them had moved into fast water. Whether this was a result of warming water which may have stimulated more active feeding or whether the trout had merely become acclimated to the stream could not be determined. Similar observations were made on an experimental planting of brown trout in the season of 1940 in this same water.

Temperature conditions remained favorable for fishing and for trout until after June 6. Stream temperatures remained well above 70° F. over twenty-four-hour periods on several occasions after this date and on three days the maximum temperatures observed ranged from 80 to 83° F. Temperatures up to 76° F. did not noticeably affect the interest of the rainbow trout in artificial lures. At higher temperatures they were occasionally attracted, but usually would not actually take the fly. At 80° F. the trout showed no visible sign of distress, other than congregation, where possible, near the entrance of leaking pond drains or areas of seepage from nearby ponds.

The fate of the trout after the termination of the experiment is not entirely known. Presumably many could have dropped downstream on high water after the weirs were removed. Some were observed dead after prolonged hot weather and low water, and some were known to have been removed surreptitiously when patroling of the stream was discontinued. A few may have been removed in this way while the experiment was in progress, but if so, the number was not large.

It is impossible to segregate the entire mass of data according to the type of lure used. It is possible to make a comparison between the relative effectiveness of the types of lure by selecting those records wherein only one type was used during the time fished In these data the average seasonal catch per hour of all trout, exclusive of the special experiments was as follows: Dry fly, 2.6 trout per hour; wet fly, 2.3 trout per hour; streamer fly, 2.2 trout per hour. Insofar as the data go, it is judged that there was little choice between the three methods of fishing. It may be noted, however, that these data are somewhat above the average catch of 2 trout per hour for all of

the data. This might find explanation in the fact that a change in method of fishing is frequently time-consuming, thus taking up some of the time that otherwise would be expended in presenting a lure to the fish. This is borne out by the data on the special experiments described below in which lure changing was reduced to a minimum (wet fly, 2.2 trout per hour; dry fly 3.1 trout per hour).

Wet Fly Experiment

The wet fly experiment was conducted to determine whether any significant differences existed between several wet fly patterns under the conditions of the experiment. Five anglers fished five patterns on five days. The variation in catch, falling to any one pattern, would be affected by three main factors: The ability or methods of the angler, the conditions encountered in the several days and the relative effectiveness of the flies. Any one of these might be of sufficient importance to obscure the results completely unless special precautions were taken to control it. This was done by assigning at random the flies to be used each day and by stipulating that each pattern be used once by each angler, and once on each day. Thus each pattern was fished each day but by a different fisherman.

The flies used for the experiment were: Royal Coachman, Black Gnat, Red Quill, Dark Cahill, and Gray Hackle. These patterns were selected because they represented a variety of fly types, i.e., different body types, wings and colors. All were dressed on Hemming No. 10 sproat hooks and patterned after standard models. In the experiment each angler used his own flies. The method of fishing was also left to the individual angler, with the qualification that he use the same general method of fishing each day. All anglers used standard tackle consisting of a 7½-foot leader tapered to 3X. The test was conducted in both morning and afternoon, each angler fishing two hours, one between 6 and 9 a.m and another between 5 and 8 p.m. This provided ten hours of fishing every day and ten hours for each fly and angler at the termination of the test. It was agreed that fish hooked and breaking away were considered as fish landed. The reason is obvious. The trout to become hooked had to make a definite decision, as it were, and once this choice was known to the angler, the essential information was at hand. In addition, all visible rises to the lure were recorded. The results are presented in Table 4.

When the possible effects of anglers and days are removed from the data by analysis of variance, no significant differences can be demonstrated for the various flies during the five-day period. On the other hand, differences between anglers and between fishing days are highly significant. This is suggested from inspection of the catch by day and by anglers in Table 4. On May 7, following a shower, the water was high, cold, and roily, and this undoubtedly accounts for the abnormally low catch on that date. The experiment was not designed

to test whether or not at *a particular time* one fly was better than another. An average of fifty per cent more rises was received than trout hooked or landed.

TABLE 4.—*Numbers of trout hooked or landed in wet fly experiment. The particular patterns accounting for the catch are appropriately abbreviated*

Angler	April 28	April 29	April 30	May 6	May 7	Angler totals
I	B.G. 3	G.H. 5	D.C. 4	R.C. 5	R.Q. 1	18
II	D.C. 0	R.C. 2	G.H. 3	R.Q. 5	B.G. 0	10
III	R.C. 3	D.C. 2	R.Q. 3	B.G. 5	G.H. 0	13
IV	G.H. 4	R.Q. 3	B.G. 8	D.C. 4	R.C. 0	19
V	R.Q. 9	B.G. 9	R.C. 11	G.H. 18	D.C. 5	52
Daily totals	19	21	29	37	6	112

Fly Totals

Dark Cahill	11
Royal Coachman	21
Black Gnat	25
Gray Hackle	30
Red Quill	25
Average number of trout per fly	22

DRY FLY EXPERIMENT

In the dry fly test, bi-visible type flies of a light gray and black were used. Half of each color was tied with large hackles and clipped, the others were tied with natural hackles, all flies being tied to the same size on light wire Hemming No. 12 perfect hooks, using a circle in a piece of cardboard 5/8 inch in diameter as a rough calibre. Four types of flies were thus available: Clipped and unclipped in both pale gray and black hackles. The test was organized the same as the wet-fly experiment, and similar rules were in effect. Fishing was conducted only on those days when stream conditions were favorable, i.e., when the water was not high and discolored. The results are presented in Table 5.

TABLE 5.—*Number of trout hooked or landed during dry fly experiment. The particular flies accounting for the catch are appropriately abbreviated.*

Angler	May 13	May 14	May 15	May 17	totals Angler
I	B.C. 7	G.C. 3	B.U. 9	G.U. 0	19
II	G.C. 8	B.U. 0	G.U. 2	B.C. 8	18
III	G.U. 10	B.C. 2	G.C. 1	B.U. 7	20
IV	B.U. 16	G.U. 6	B.C. 7	G.C. 5	34
Daily totals	41	11	19	20	91

Fly Totals

Light Gray unclipped	18
Light Gray clipped	17
Black unclipped	32
Black clipped	24
Average number of trout per fly	25

When the data are analyzed in a manner similar to those the wet fly experiment, no significant differences can be shown between flies, anglers, or days. Unfortunately, the influence of factors other than the three which were measured reduced the precision of the test. However, it may be noted that of flies, anglers, and days, flies affected the catch the least, days the most. Forty-five per cent of the number of rises resulted in hooked fish.

The apparent superiority of the dark patterns is worth attention. In fact, on the last two days of the experiment, the anglers participating remarked that the black flies appeared decidedly better than the light gray ones, disregarding for the moment the fishing ability of individual anglers. Since it so happened that May 15 and 17 were overcast dark days, this opened up an argument about weather conditions in relation to the light vs. dark fly question. In Table 6 a summary is given of the data of Table 5 with regard to fly color and weather; other things being equal, the black flies certainly appear superior during the two overcast days, the results in the other days being somewhat inconclusive. At any rate, the subject is worthy of future and additional investigation.

TABLE 6.—*Number of trout caught on light and dark dry flies and general weather conditions*

Item	May 13	May 14	May 15	May 17
Light flies (gray)	18	9	3	5
Dark flies (black)	23	2	16	15
Sky	Partly cloudy	partly cloudy	Overcast	Overcast

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THE COMMERCIAL MARINE FISHES, CRUSTACEANS AND MOLLUSCS OF THE WEST COAST OF MEXICO

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INTRODUCTION

Pursuant to the provisions of the laws of the United States authorizing the executive departments and independent establishments of the Federal Government to cooperate in undertakings of mutual and reciprocal interest with the departments and agencies of the governments of the twenty-one American Republics,[1] the Fish and Wildlife Service has cooperated since 1940 with the Mexican fishery department (Secretaría de Marina, Dirección de Pesca e Indústrias Conexas). This cooperation consists of the assignment of two aquatic biologists of the Fish and Wildlife Service, one for marine fisheries and one for fresh-water fisheries, to assist the Mexican Government in the conduct of scientific investigations and in developing plans for the rehabilitation, management and conservation of the fishery resources.

Since a large proportion of the products of Mexican fisheries finds its way into markets in the United States, either through import or in American vessels, a resumé of the Mexican fishery resources is believed to be of more than casual scientific interest.

The most productive areas for fisheries along the west coast of Mexico are the waters surrounding the Peninsula of Lower California, including the Gulf of California. This results from the fact that there is probably a greater abundance of fishes in these waters as well as from the fact that this area is more available to the markets of the United States than are those regions farther to the south.

Note: The poundages recorded in this paper are based upon published data of the Mexican "Dirección de Pesca e Indústrias Conexas" for the year 1941 with various conversion factors applied.

FISHES

The greatest fishery along the west coast of Mexico is that of the tunas and tuna-like fishes, which in 1941 amounted to over 55,000,000

[1]The Act of May 3, 1939 (Title 5 U. S. Code, Sec. 118e); and the Act of August 9, 1939 (Title 22 U. S. Code, Sec. 501).

pounds. By far the larger portion of these species is taken by boats flying the American flag and sailing from the ports of San Diego and San Pedro, California. There is, however, a tuna cannery near the tip of the Lower California peninsula at San José del Cabo.

The tuna usually are caught with two types of gear. One is the hook-and-line fishery operating from bait boats which use live fishes such as sardines and anchovettas to chum the tunas. The other is the purse-seine type of fishery where a large net is used to encompass a school or a portion of a school of fish. No bait is used by the purse-seiners.

Although tuna are caught along the entire extent of the west coast of Mexico, over the outlying banks and around the islands, and north in the Gulf of California to Angel de la Guarda Island, the greater quantities are captured along both coasts of Lower California.

Of the tunas that occur in Mexico the yellowfin tuna (*Neothunnus macropterus*), known in Mexico as "atún" or "atún de aleta amarilla," the skipjack (*Katsuwonus pelamis; "barrilete"*), and the bluefin tuna (*Thunnus thynnus;* "atún" or "atún de aleta azul") are the more abundant forms. However the highly prized albacore (*Germo alalunga; "albacora"*) has reappeared in increasing abundance along the Pacific northern half of Lower California during the past 3 years. The bonito—both the California bonito (*Sarda lineolata*) and the Mexican bonito (*S. velox*)—are taken in considerable quantities; the California bonito in the more northern section and the Mexican bonito from at least Cape San Lucas to the Guatemalan border. Both these species are known by the name of "bonito" in Mexico and occasionally they are mistaken for the skipjack and referred to as "barrilete."

The yellowtail, of which three species occur along the west coast of Mexico, although not a tuna, is referred to in California as a "tuna-like fish." The more abundant forms are *Seriola dorsalis* and *S. colburni*, which in Mexico are called "jurel." The name "jurel" is not restricted to the genus *Seriola*, but is generally used for any of the jack fishes and particularly for those of the genus *Caranx*. Another tuna somewhat similar to the yellowfin but apparently not particularly abundant, has been reported from Mexico. This is the big-eye tuna (*Parathunnus mebachi*).

The California sardine or pilchard (*Sardinops caerulea;* "sardina") and the Pacific mackerel (*Pneumatophorus diego;* "macarela") occur in considerable abundance along the northwest coast of Lower California. In this region two canneries packing these fishes are located at Ensenada, Lower California. The product is not exported to the United States as better prices can be obtained in Mexico. Some of the sardines are converted into oil and meal. In 1941 over 6,000,000 pounds of sardines and 5,000,000 pounds of mackerel were taken by the Mexican fishermen. The California sardine appears to be limited to the waters adjacent to the Peninsula of Lower California. The

mackerel, on the other hand, occasionally is found as far south as Manzanillo, Colima.

For many years prior to 1940, Mexico had a small shark fishery. This was primarily for shark fins for the Chinese export trade and for liver oil to be used in the tanning and soap industries. Each year some shark were taken for local consumption in the fresh state and some meat was salted and dried. Occasional efforts were made to utilize the hides for leather.

However, with the sudden increased demand for vitamin "A" and with the discovery that many sharks along the west coast of Mexico possessed livers containing a relatively high concentration of this vitamin, the shark fishery underwent a sudden and rapid expansion. In 1941 over 1,500,000 pounds of vitamin-rich shark livers were exported to the United States for processing. Since 1942 there has been a decline in production which may possibly be associated with overfishing.

Since the war there has been a considerable increase in the production and utilization in Mexico of salted, dried shark meat. This product sells throughout Mexico, especially during the lenten season, and is known as "bacalao" (codfish) or "bacalao del país." It has largely taken the place of the imported codfish which it closely approximates in flavor.

The important shark fishery exists from Lower California to Oaxaca. The principal ports are Ensenada, Lower California; La Paz, Lower California; Guaymas, Sonora; Mazatlán, Sinaloa; Manzanillo, Colima; and Acapulco, Guerrero. There are probably over 25 different species of sharks taken along the west coast of Mexico. Most of these, important for the high potency of their livers, belong to two families—the requiem sharks of the family Galeorhinidae (the family to which the well known Pacific soupfin-shark belongs) and the hammerhead sharks, family Sphyrinidae. In Mexico the general name for shark is "tiburón" and small sharks are frequently called "cazón." However, most of the commoner sharks have specific local names which vary considerably according to the locality. The hammerheads are known as "cornuda," "cornuda arqueada," "cornuda bava," and "martillo." Two of the more common members of the genus *Eulamia* are the "gambuso" and the "injerto" which are high in vitamin potency.

Most of the shark fishing in Mexico is conducted by means of the "cimbra," a long set-line with from 20 to 50 hooks baited with almost any type of fish, but preferably with dark-meated animals such as the porpoise ("tonina") or the bonito. Some of the sharks are taken by gill nets and still others by beach-seines.

The totoaba (*Cynoscion macdonaldi*), the largest member of the croaker family occurring on the Pacific coast, is limited in its distribution to the Gulf of California. Near the head of the Gulf it is captured on both the Lower California and the Sonora sides whereas in

the central and lower reaches it seems to occur in abundance only on the Sonora and Sinaloa side. This fish was originally taken for its swim bladder which is known as "buche" in Mexico. Many thousands of pounds of totoaba were taken each year, opened, the swim bladder removed, and the remainder of the carcass allowed to rot on the beaches. The swim bladder was dried and sold to the Chinese who highly prized it as an ingredient of soups. Since about the middle twenties however the "buche" phase of the fishery has become secondary to the utilization of all of the edible portions of this fine food fish for human consumption. Several million pounds are exported each year to the United States by truck and by rail.

Practically nothing is known of the life history of the totoaba although it does appear to have a definite migratory path within the Gulf in the fall and early winter. The totoba is taken principally with hook and line by native fishermen in dugout canoes. A fair amount however is taken with gill nets. By Mexican law the commercial capture of totoaba is restricted solely to those native fishermen banded together in cooperatives.

The mullets ("lisa"), both *Mugil cephalus* and *Mugil curema*, are found in considerable abundance in the bays and estuaries along the Mexican west coast. *M. cephalus* attains a considerably larger size than does *M. curema*. Although taken in large amounts, neither are highly prized as delicious food fishes and they are generally consumed in quantities only in the regions where they are abundant. In 1941, almost 3,000,000 pounds of mullet were recorded for the west coast of Mexico.

The greatest fishery for mullet occurs in the state of Chiapas where the majority are taken by cast nets ("atarrayas") and seines, split open, lightly salted, and sun-dried. They are consumed throughout the entire state during Lent and some are exported each year to Guatemala. The state of Sinaloa is the next largest producer of mullet. Here in the vicinity of Escuinapa, they are taken by cast nets and weirs ("cierras") and are canned "salmon style." If a market were available undoubtedly much greater quantities of mullet could be produced.

The barracuda, of which two species, the California barracuda (*Sphyraena argentea*) and the Mexican barracuda (*S. ensis*) occur along the west coast of Mexico, is not greatly utilized by the Mexicans for local consumption. More than 1,500,000 pounds were exported to the United States in 1941. The greater portion was taken by United States boats fishing under Mexican licenses along the west coast of Lower California. In Mexico, the barracuda is known as "barracuda" or "picuda."

The milkfish (*Chanos chanos*), known along the west coast of Mexico as "sabalote" and "sábalo," occurs from Sonora to Chiapas. In excess of 1,000,000 pounds are taken each year, mostly in the bays of Oaxaca

and Chiapas east of Salina Cruz. They are captured by seines and cast nets operated from dugout canoes and are generally salted and sun-dried. Because of a similarity of common names and a superficial similarity in appearance this fish is frequently mistaken for the tarpon (*Tarpon atlanticus;* "sábalo") of the east coast of Mexico.

The robalos (genus *Centropomus*), of which at least four species occur along the west coast of Mexico, ordinarily are taken in the lagoons and estuaries by seines and by hook-and-line. Known in Mexico as "robalos," and one small species as "chucumite," they are more abundant from Nayarit to Chiapas. They are considered a good food fish by the Mexicans and approximately 1,000,000 pounds are taken annually. The major quantity taken in Oaxaca and Chiapas are dried, whereas in the states to the north they are ordinarily consumed fresh.

The snappers (family Lutianidae) are represented by at least eight species along the west coast of Mexico. They are found from Lower California to Chiapas although the greater abundance appears to be from the Gulf of California to Chiapas. They are known in Mexico by the names "huachinango" and "pargo." In general the snappers occur around the rocks and reefs where they are taken by baited hand lines. However at least one species enters the bays where it is taken by seines and cast nets. The "huachinangos" and "pargos" are usually considered a prize food fish in Mexico and in 1941 more than 800,000 pounds were reported taken by Mexican fishermen for local consumption.

The groupers, cabrillas and rock basses (genera *Mycteroperca, Epinephelus* and *Paralabrax*) of which approximately nine species are found along the west coast of Mexico, are of commercial importance primarily along the west coast of Lower California and throughout the Gulf of California. These fishes are known in Mexico as various types of "cabrilla." The names "baya" and "pintillo" are used for specific fishes of the above genera. In 1941 over 600,000 pounds were taken, mostly for export to the United States. Although these fishes are highly prized in Mexico, only a few find their way to the markets of Mexico City due to the difficulties of transportation.

The weakfishes (genus *Cynoscion*), at least four species of which (exclusive of the totoaba) occur in Mexico, are known as "corvinas" or "corbinas." They are most abundant in the Gulf of California and along the west coast of Lower California. Approximately 400,000 pounds were taken in 1941 and like the other fishes in this area the majority were destined for markets in the United States. One species occurring in the Gulf of California is known as "cabaicucho."

Two fishes are known in Mexico as the "mero": The black sea bass (*Stereolepis gigas*) which occurs on the west coast of Lower California as far south as Magdalena Bay, and the southern jewfish (*Promicrops itaiara*) which occurs from the Gulf of California to Chiapas. These fishes,of which in excess of 300,000 pounds were reported for 1941, are

taken in commercial quantities only along the west coast of Lower California and in the Gulf of California. Most are exported to the west coast of the United States.

The mojarras (family Gerridae), of which several species belonging to the genera *Eucinostomus, Gerres* and *Diapterus* occur along the west coast, are a well-liked food fish. The largest fishery for mojarras occurs in the lagoons of the state of Chiapas where over 75,000 pounds were taken in 1941. In Chiapas *Gerres cinerus* and *Diapterus lineatus* are most abundant and no distinction is made between them by the fishermen who call both "mojarra." Most are taken in seines and cast nets and are sold fresh, lightly salted, dried, fried and roasted.

Various species of catfish ("bagre") are found along the west coast but the heaviest fishery is that for *Sciadeichthys troschelii* in the Chiapas and Oaxaca lagoons where 55,000 pounds or more were taken in 1941. They are taken in seines and cast nets in conjunction with "sabalote," "lisa" and "mojarra." The majority are prepared for sale by lightly salting and then sun-drying.

The California halibut (*Paralichthys californicus*), a flounder, is most abundant along the northwest coast of Lower California. This is another species that is marketed in the United States. Over 80,000 pounds were recorded for 1941. Flounders as a rule are not particularly abundant south of Cape San Lucas, Lower California and are not common in the markets. They are usually known by the name of "lenguado" although in Salina Cruz, Oaxaca both *Cyclopsetta panamensis* and *C. querna* are called "bocado de Dios."

The Spanish mackerel or "sierra" (*Scomberomorus sierra*) is found along the entire coast and is quite plentiful from Sonora to Chiapas. Although an excellent food fish the Spanish mackerel is not utilized in proportion to its abundance as only 30,000 pounds were reported for 1941. Two small canneries at Guaymas, Sonora pack this mackerel under the name "Pescado Rosado estilo Salmón."

The lookdown, of which two species, *Argyreiosus brevoorti* and *A. oerstedii,* occur along the Mexican west coast, is more frequently used for food in the states of Oaxaca and Chiapas. In this region it is usually called "chapeta," whereas to the north it is known as "jorobado." *A. brevoorti* appears to be the more abundant of the two. The reported catch of lookdown for 1941 exceeded 18,000 pounds.

The garfish (*Lepisosteus*) is used for food in Mexico and is usually called "catán" although in Chiapas it goes by the name of "cherna." More than 15,000 pounds were taken in 1941.

The ocean whitefish (*Caulolatilus princeps*) is taken in small amounts on the west coast of Lower California. Approximately 7,000 pounds were recorded for 1941 almost all of which were exported to the United States. This fish is called "pescado blanco del mar."

The swordfish (*Xiphias gladius*) and the marlins (*Makaira mitsu-*

kurii and *M. marlina*) are primarily sportfish in Mexico although over 5,000 pounds of swordfish ("pez espada") were reported taken off the Lower California coast by boats from the United States. These fishes together with the sailfish (*Istiophorus greyi;* "pez vela") are each year inducing more and more sportfishermen to the west coast of Mexico—particularly to Acapulco, Guerrero and Guaymas, Sonora. When able to obtain them the natives, particularly at Acapulco, eat all of these species.

In addition to the above fishes many other species can be found in the markets of the various coastal towns. Most are not particularly abundant although if demand were greater some could be taken in considerably larger quantities than at present. Of these the more important are: "roncador" or "ronco" (*Umbrina sinaloe* and *Roncador stearnsi*); "papagallo," "pez gallo or "gallo" (*Nematistius pectoralis*); "dorado" (*Coryphaena hippurus*); "pampano," "paloma" or "palometa" (*Trachinotus* species); "macabí" or "quijo" (*Albula vulpes*); "burros" (*Pomadasys* species) and the "aguja" or "agujón" (species of the genera *Hyporhamphis* and *Strongylura*).

As an example of the variety of forms that appear in the local markets there follows below a list of the species, with their local and scientific names, encountered in the Salina Cruz, Oaxaca market between April 1 and April 6, 1943:

Alacrán (*Umbrina sinaloe*)
Bandería (*Gnathanadon speciosus*)
Blanquito (*Lythrulon flaviguttatum*)
Blanquito (*Orthostoechus maculicauda*)
Bocado de Dios (*Cyclopsetta panamensis*)
Bocado de Dios (*Cyclopsetta querna*)
Boca dulce (*Polynemus approximatus*)
Chapeta (*Argyreiosus brevoorti*)
Chivo (*Upeneus grandisquamis*)
Cocinero (*Caranx caballus*)
Corbina (*Cynoscion parvipinnis*)
Corbina (*Isopisthus remifer*)
Cuatro ojos (*Anableps dovii*)
Huachinango (*Lutianus* sp.)
Lisa (*Mugil cephalus*)
Lisa (*Mugil curema*)
Machete (*Elops affinis*)
Mojarra (*Gerres cinereus*)
Ojotón (*Xenichthys xanti*)
Pargo flamenco (*Lutianus guttatus*)
Pelón (*Oligoplites mundus*)
Picuda (*Sphyraena ensis*)
Poyote (family Gobiidae)

Quijo (*Albula vulpes*)
Robalo (*Centropomus sp.*)
Roncador (*Ophioscion sp.*)
Sabalote (*Chanos chanos*)
Suleme or Palometa (*Trachinotus sp.*)
Zapatera (*Chaetodipterus zonatus*)

Of the crustaceans there were shrimp ("camarón"; *Penaeus californiensis* and *P. vannamei*); crabs ("jaibas"; *Euphylax dovii* and *Callinectes toxotes*); and goose-barnacles ("percebes"). There was also a small clam "almeja" which was not identified.

Crustaceans

The shrimp is the most important solely Mexican-caught fishery product of the west coast. Most of the catch nevertheless is destined for export to the United States. In 1941 15,000,000 pounds or more of shrimp were taken along the west coast of Mexico. The major production comes from the region between Guaymas, Sonora and Cape Corrientes, Jalisco. Another rather large fishery exists in the State of Chiapas. There are several species that appear in the fishery, although the principal forms are *Penaeus stylirostris, P. vannamei* and *P. californiensis.* In the area north of Mazatlan, Sinaloa *Penaeus stylirostris* ("camarón" or "camarón azul") is the most abundant species. Between Mazatlan and Cape Corrientes, *Penaeus vannamei* ("camarón") appears to be the most abundant form and in Chiapas, both *Penaeus vannamei* and *P. californiensis* ("camarón") occur in some abundance.

Until about 12 years ago practically all of the shrimp taken in these areas were caught by means of cast nets ("atarrayas") thrown from dugout canoes or by weirs ("cierras"). The catch was boiled and dried. The majority of the product was sold with heads and shells on, although some was peeled. In the early 1930's an American company began using otter trawls and exported iced or frozen shrimp to the United States. Later several Japanese companies entered the fishery with large factory ships equipped with freezing plants and accompanied by a group of large steel trawlers. The catch was exported principally to Japan and California. After the departure of the Japanese in 1940, the Mexicans built two freezing plants, one at Guaymas, Sonora and the other at Topolobampo, Sinaloa. At the beginning of this endeavor a number of trawl boats were secured from the United States but later a shipbuilding yard was established at Guaymas for local construction of trawlers. Several new freezing plants are now under construction and the production is increasing each year.

The majority of the shrimp destined for the frozen or the fresh-headless trade are now taken by trawlers operating along the coast between Guaymas, Sonora and Altata, Sinaloa. A fair quantity, how-

ever, are taken in the bays and lagoons with cast nets operated from dugouts ("canoas"). The shrimp taken by these methods are beheaded and either frozen in 5 pound blocks or packed in ice in boxes and shipped to the United States. Practically all of the frozen and fresh-headless shrimp from this region is exported to the United States. During the 1944-45 season in excess of 7,000,000 pounds of headless shrimp were exported to the United States of which approximately 5,500,000 pounds were frozen-headless shrimp and the remainder fresh-headless. These shrimp average considerably larger than those taken in the United States fisheries in the Gulf of Mexico or along the South Atlantic coast.

The Chiapas shrimp fishery is purely a cast net fishery with most of the catch boiled in brine and dried. This fishery is conducted exclusively in the brackish mud-bottomed lagoons and for this reason only small shrimp are taken. Almost 1,000,000 pounds of unpeeled dried shrimp are produced annually.

The catching of shrimp in Mexico is now limited to native fishermen belonging to legally authorized cooperatives.

Although two species of spiny lobsters ("langostina"; *Panulirus interruptus* and *P. inflatus*) occur in Mexico, *P. interruptus* is by far the more important commercial form. It is found in considerable abundance along the west coast of Lower California where it is captured in traps. In 1941 1,600,000 pounds of lobsters were taken. Almost all of these were exported to markets in the United States. Small quantities of lobsters are taken for local consumption at various ports along the entire coast of Mexico.

Molluscs

The abalones ("abulones"), of which four species are commercially important in Mexico, [red abalone ("abulón rojo"; *Haliotis rufrescens*), green abalone (abulón verde"; H. *fulgens*), pink abalone ("abulón rosa"; *H. corrugata*) and black abalone ("abulón negro"; *H. cracherodii*)] are taken along the west coast of Lower California. This fishery is the most important mollusc fishery of Mexico. More than 2,000,000 pounds of abalones were taken in 1941, almost all of which were canned locally for export to the United States and reexport to the Hawaiian Islands and the Orient. Divers gather the abalones by prying them off the rocks.

The largest oyster fishery on the west coast is near Guaymas, Sonora. This oyster (ostión") is reported to be *Ostrea chilensis*. It is gathered by hand from the flats at low tide. No attempt has been made to cultivate this mollusc and as a result the fishery is extremely sporadic. In 1941 over 60,000 pounds of oyster meats were produced. Most of the oysters are canned in Guaymas although some are shipped in the shell or shucked and iced for sale in Mexico City.

At least five species of oysters have been reported from the west coast of Mexico but other than the fishery near Guaymas they are of little importance.

A number of species of clams (almejas'') occur along the west coast of Mexico but with the exception of the Pismo clam (*Tivela stultorum*) they are of only local importance. In 1941 over 25,000 pounds of Pismo clams were exported to the United States from the west coast of Lower California. Since then this fishery has grown considerably in magnitude until it now ranks next to the abalone in volume of production.

Various species of squid (''calamar'') are found and taken along the entire west coast. They are not of great commercial importance although generally prized by the fishermen. A few are canned each year at Esenada, Lower California. Slightly over 2,500 pounds were reported for 1941.

The once important pearl oyster fishery (''concha madre perla'') has dwindled into obscurity. Apparently the abundance of this mollusc (*Pinctada mazatlanica*) has diminished in an alarming fashion. The fishermen claim an unknown disease has been the cause of practically wiping out the population of pearl oysters. In 1941 only 15,000 pounds were taken. At one time La Paz, Lower California was the second most important pearling port in the world.

THE RIBOFLAVIN AND PANTOTHENIC ACID REQUIREMENT OF BROOK TROUT

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ABSTRACT

Experiments were conducted to determine the riboflavin and pantothenic acid requirement of brook trout. Groups of trout were fed diets containing different levels of the vitamins and after a period the fish were killed and their livers analyzed micro-biologically to determine the amount of storage of the vitamins. It was found that up to a maximum, the amount of storage increased with the level of the vitamins in the diet. When a maximum level was reached in the liver additional amounts in the diet did not increase the liver content. It has been tentatively concluded that brook trout require between 0.36 and 0.53 milligrams of riboflavin per kilogram of body weight daily and between 1.11 and 1.45 milligrams of pantothenic acid.

Anemic fish contained low levels of both these vitamins, supporting the conclusion of Tunison *et al.* (1943) that they play a role in trout anemia. A deficiency of pantothenic acid resulted in a gill disease, confirming the results of Wolf (1943), but it is thought that it is the western type described by Fish (1935) as no bacteria were found.

INTRODUCTION

The vitamin requirements of trout have been of considerable interest to fishery workers for many years and a number of papers have been published in which a need for vitamins was reported. However, it is only recently that actual vitamin deficiencies have been recognized.

Wolf (1942), Tunison *et al.* (1942) and Woodbury (1942) have all reported a deficiency disease of trout due to a lack of vitamin B_1. Simmons and Norris (1941) concluded that xanthopterin was useful in curing a nutritional anemia of trout. Totter *et al.* (1944) have given an excellent summary of the relationship of xanthopterin to the B complex and anemia. Wolf (1943) stated that bacterial gill disease was a result of a deficiency of pantothenic acid. Gutsell (1939) reported a favorable response of rainbow trout to cod liver oil, thus confirming the earlier work of Davis (1927). Tunison *et al.* (1942) studied the effect of low vitamin A diets upon the storage in the body and demonstrated that such diets resulted in low amounts of vitamin A in the various organs of trout. Tunison et al (1943) were able to cure anemia resulting from feeding a synthetic diet by adding a combination of riboflavin, pantothenic acid and pyridoxine to the diet. To date but few attempts have been made to establish the daily requirements of trout for the various vitamins.

Vitamin studies upon fish have been greatly hampered by an insufficient knowledge of their nutritional requirements, which has prevented the compounding of a synthetic diet. Since definite deficiencies have been recognized only recently, little work has been done along the usual lines of vitamin studies. The older methods of vitamin assays have not been readily adaptable to trout studies. The rat assay methods are not only expensive, but they require an amount of material that is impractical for this type of investigation. Chemical methods have not filled the need because either they require highly specialized apparatus or are limited as to the types of materials that may be used. The newer micro-biological assay methods have offered an excellent opportunity for experimentation upon the vitamin requirements of fish. Such methods require only a small amount of test material, and no highly specialized equipment is needed. Because many of the vitamins are stored by the body only to a limited extent, it is possible by analyses to determine the quantity of vitamin needed in the diet to reach maximum storage in some organ of the body.

During the summer of 1944 two members of the vitamin B complex, riboflavin and panthotenic acid were investigated as to their need in trout nutrition.

Method

Through the use of different mixtures of dry concentrates and meats, diets were fed to brook trout (*Salvelinus f. fontinalis*) fingerlings which contained various levels of the vitamins under study. The experiments were started in early May, using brook trout with an average weight of from 0.5 to 0.6 gram. Trout were killed in August and September and the livers removed for analysis. At the time of analysis the trout averaged from 2 to 6 grams in weight, depending upon the diet they had been fed. Such variation in average weight would be expected due to the effect of the various food mixtures upon the rate of growth.

The fish were held in experimental troughs supplied with water at 47° F. The fish were weighed and fed according to the established procedure of the Cortland Experimental Hatchery (Tunison *et al.*, 1939).

The liver tissue was prepared for riboflavin assay according to the procedure of Strong and Carpenter (1942) and for pantothenic acid assay following the method of Neal and Strong (1943). The prepared livers were then assayed by the method of Landy and Dicken (1942), using *Lactobacillus casei* as the test organism. The response of the bacteria was measured by means of a photoelectric colorimeter 24 hours following the innoculation of the cultures. All results are an average of at least two samples of livers and each sample was composed of several aliquots selected to fit the range of the standards.

Analyses were also made upon the various ingredients used in the

diets. Although many values for these could be found in the literature, the wide range of the published values appeared to warrant repeating the analyses so that our diets could be better standardized.

Discussion of Results

Table 1 lists the composition of the various diets fed the experimental fish. The riboflavin and pantothenic acid content of these mixtures are shown in the last two columns of Table 3.

Table 2 is a summary of the values of riboflavin and pantothenic acid found in this laboratory for the various components of the diets. Values from three sources in the literature have also been included for comparative purposes. In general close agreement was found between our values and those of the literature. However, in several instances wide differences are found. This is especially true of riboflavin in cottonseed meal and pantothenic acid in fish, soy bean and corn gluten meal. Such variations might be expected in analyses of such widely separated lots of feedstuffs.

Table 1.—*Diet composition, in grams*

Diet number	Fresh beef liver	Treated beef liver[1]	Hog melts	Dry feed number 12[2]	Dry feed number 23[3]	Salt	Synthetic diet[4]	Pantothenic acid milligrams
801	....	....	50	50	....	....	....	....
805	....	15	35	50	....	....	....	....
808	50	....	48	....	....	2	....	....
820	98	....	....	....	....	2	....	....
823	....	....	50	....	50	....	....	....
825	....	....	50	....	50	....	....	5
844	....	....	....	....	....	....	100	....

[1]Treated beef liver—fluke infested beef liver, denatured by dying as required by law.
[2]Dry feed number 12—24 parts each of dried skim milk, cottonseed meal, wheat middlings and white fish meal and 4 parts of salt.
[3]Dry feed number 23—24 parts each of corn gluten meal, cottonseed meal, soy bean meal, wheat middlings and 4 parts of salt.
[4]Synthetic diet—20 parts casein, 4 parts Osborne Mendel salt mixture, 5 parts yeast, 3 parts cod liver oil and 34 parts each of raw corn starch and dextrin.

Table 2.—*Riboflavin and pantothenic acid content of foodstuffs*

Food stuff	Riboflavin gamma per gram foodstuff			Pantothenic acid gamma per gram foodstuff		
	Cortland value	Literature value[1]	Literature value[2]	Cortland value	Literature value[1]	Literature value[2]
Fresh beef liver.....	40.5	30.0[3]	.....	55.3	60.0(3)	.....
Treated beef liver[4]..	19.5	.....	.....	69.0	.....	.....
Hog melts	7.6	.....	.....	16.6	.....	.....
White fish meal.....	9.6	10.0	8.8	12.2	2.8	.....
Dried skim milk....	22.5	21.0	20.5	44.5	42.0	33.4
Soy bean meal.....	3.3	4.0	4.1	20.0	14.0	13.8
Cottonseed meal	4.0	0.7	8.7	11.4	14.0	13.9
Wheat flour middlings	3.1	2.0	1.7	12.0	11.2	9.9
Corn gluten meal....	1.9	0.0	1.7	1.8	.....	13.7

[1]Archer-Daniels-Midland Co., 1942.
[2]Ellis and Madsen, 1943.
[3]Waisman and Elvehjem, 1941.
[4]Treated beef liver—fluke infested beef liver denatured by dying as required by law.

Table 3 is a summary of the results of the analyses of the various lots of fish and records the level of vitamins fed each group.

The first and third columns of Table 3 are a comparison between the various amounts of riboflavin in the diet and that stored in the liver. The riboflavin content of the liver was not affected by that of the diet until the level was reduced to 6 gamma of the vitamin per gram of diet. Feeding levels up to 24 gamma per gram did not increase the level of riboflavin in the liver above that fed the diet containing 9 gamma per gram. It is concluded that brook trout under the conditions of these experiments can maintain the level of riboflavin in their livers when fed daily a diet which contains somewhere between 6 and 9 gamma of the vitamin per gram.

The second and fourth columns of Table 3 illustrates a similar comparison for pantothenic acid. The vitamin level was maintained when 26 gamma per gram of food were fed, but dropped when the level was reduced to 19 gamma per gram. It was not increased when levels as high as 134 gamma per gram of food were fed. The critical level of pantothenic acid appears to be between 19 and 26 gamma of the vitamin per gram of diet.

TABLE 3.—*Vitamin content of the livers of the various groups, together with the level of each vitamin fed in the diets*

Diet number	Riboflavin gamma per gram liver	Pantothenic acid, gamma per gram liver	Riboflavin gamma per gram diet	Pantothenic acid gamma per gram diet
801	18.3	14.0	8.9	18.5
805	17.2	24.5	10.6	26.4
808	17.5	23.0	24.0	35.9
820	18.0	22.5	40.5	55.3
823	13.0	8.0	6.0	14.1
825	12.0	23.0	6.0	134.1
844	4.2	5.5	4.8	12.0

Since the experimental fish were fed a definite amount of food in terms of their body weight, it was possible to reduce the data in terms of milligrams of the vitamins fed per kilogram of body weight. This has been done in Table 4, which also lists the average weight of the fish at the time of analysis and the amount fed. From the milligrams fed per kilogram of body weight, as shown in Table 4 and the amount of vitamin stored in the liver, as shown in Table 3, it is tentatively concluded that brook trout held under our conditions should receive from 0.36 to 0.53 milligrams of riboflavin per kilogram of body weight daily and should have available from 1.11 to 1.45 milligrams of pantothenic acid.

These requirements are suggested as tentative because several problems still remain unanswered. Since the body metabolism of a trout varies with the water temperature, entirely different values might be obtained at either higher or lower water temperatures. It is possible that trout utilize the vitamins more efficiently from meats than concen-

trates and more fully from meat concentrates than plant meals. Requirements should be established both for different species of trout and for trout of different sizes. However the relation found between the amount of vitamin in the diet and the quantity stored in the liver does appear to offer a good starting point for the problem.

TABLE 4.—*Milligrams of vitamins fed per kilogram of body weight*

Diet number	Average weight fish	Per cent of body weight fed daily	Milligrams[1] riboflavin fed per kilogram trout daily	Milligrams[1] pantothenic acid fed per kilogram trout daily
801	4.12	6.0	0.534	1.11
805	6.1	5.5	0.583	1.45
808	5.51	5.5	1.320	1.97
820	4.70	5.5	2.227	3.04
823	1.95	6.0	0.360	0.85
825	2.54	6.0	0.360	7.62
844	1.68	6.0	0.288	0.72

[1]To convert to gamma, multiply by 1000.

PATHOLOGICAL CONDITIONS

Experiment 844 was fed a synthetic diet and the fish were severely anemic at the time the analyses were made. The extremely low values for both riboflavin and pantothenic acid appear to support the conclusion of Tunison *et al.* (1943) that these elements are essential for anemia prevention. It is interesting to note that Lot 823 was not anemic although the amount of vitamins fed was not much greater than that of Group 844. It is possible that the fish did not fully use the vitamins present in Diet 844 due to water loss. A synthetic mixture is extremely hard to feed to fish without considerable loss in the water.

Experiments 823 and 825 listed in Table 3 produced extremely interesting results. During the experimental period an excessive mortality appeared in Trough 823. An examination showed a great amount of clubbing and fusion of the gill filaments, typical of the lesions usually associated with bacterial gill disease. Repeated examinations during the test period failed to produce bacteria and the gills were not coated with the usual mucous of bacterial gill disease. It is possible that this might be the true western type of gill disease described by Fish (1935) in which causative organisms were never found. This diet contained a low level of pantothenic acid and the amount of acid in the trout liver was also quite low. Experiment 825 was fed the same diet with the addition of twice the level of pantothenic acid found in beef liver. No gill lesions developed during the course of the experiment. This suggests that pantothenic acid is responsible at least in part for the gill condition. A portion of Trough 823 was removed and fed the same diet as Trough 825. The lesions quickly disappeared. This work confirms that of Wolf (1943) in that a lack of pantothenic acid was found to be responsible for a gill disease,

but it is felt that it is the western type rather than a bacterial gill disease. That pantothenic acid is not the entire cause for this condition is suggested by Experiment 844. Even though the levels in both the livers of the fish and the diet were very low, only a very slight clubbing was noted during the course of the experiment. Either some other factor is also responsible in part for this condition or the fish in experiment 844 became anemic and died before a prolonged lack of pantothenic acid could cause the gill trouble.

Conclusions

1. Tentative conclusions are offered that brook trout varying from 2 to 6 grams in average weight should receive between 0.36 and 0.53 milligrams of riboflavin per kilogram of body weight daily.

2. Tentative conclusions are drawn that the brook trout used in these experiments required between 1.11 and 1.45 milligrams of pantothenic acid per kilogram of body weight daily.

3. The amount of riboflavin and pantothenic acid stored in the liver of brook trout is dependent upon the amount present in the diet to a certain maximum beyond which additional amounts of the vitamins will not alter the liver content.

4. Anemic trout were found to have low storages of both riboflavin and pantothenic acid in their livers.

5. A deficiency of pantothenic acid resulted in a gill condition showing lesions similar to those of bacterial gill disease. Bacteria were not found. It is suggested that this might be the cause of the Western Type of gill disease.

6. Indications were found that pantothenic acid might not be the sole cause of the deficiency gill disease in that anemic fish did not show the typical lesions. However, it is possible that these fish became anemic and died before the lesions could develop.

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AGE AND GROWTH OF THE KIYI, *LEUCICHTHYS KIYI* KOELZ, IN LAKE MICHIGAN

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CONTENTS

	Page
Abstract	89
Introduction	90
Materials and methods	91
Age composition	92
Length and weight at capture; length-frequency distributions	96
Comparison of the growth of the kiyi in Lakes Michigan and Ontario	107
Calculated growth in length and weight	108
Growth of the age groups and general growth in length	108
General growth in weight	113
Growth compensation	116
Amount of season's growth completed at time of capture	118
Length-weight relationship	122
Seasonal, annual, and local differences; general relationship	122
Loss of weight at spawning	127
Effect of gill net selection on the estimation of the value of the coefficient of condition	128
Maturity	133
Sex ratio	133
Sex ratio in summer collections	133
Sex ratio in spawning-run collections	136
Changes in sex ratio with increase in age	137
Conservation of the kiyi	140
Literature cited	141

Abstract

Ages were determined and individual growth histories were calculated from the examination and measurement of the scales of 1,649 kiyis captured at seven localities in Lake Michigan in 1931 and 1932. The numbers of individuals employed for the investigation of other phases of the life history (such as length-frequency distributions, length-weight relationship, and sex ratio) varied according to the amount of data available or required.

Age-group IV was dominant in the 1931 collections from Racine, Port Washington, and Kewaunee, Wisconsin, and age group V dominated the 1932 samples from the Fox Islands and from three localities southward of Manistique, Michigan. A trend was noticeable toward an increase in average age from south to north. Among the explanations suggested for the observed differences in age composition were: Variation with latitude in the natural span of life; differences in fishing intensity; fluctuations in the strength of year classes (to account possibly for the shift in the dominant age group from 1931 to 1932). The oldest male kiyi belonged to the VII group and the oldest female was a member of the X group.

The possible distorting effects of such factors as gear selection traceable to differences in the mesh sizes of nets fished in 1931 and 1932, selection by nets on the basis of the condition (K) of the fish, and local variations in fishing intensity and hence in the selective destruction of rapidly growing individuals in the fishery were held to be sufficiently great to render doubtful the significance of most of the observed local differences in growth rate. Kiyis from all samples were combined to determine the general growth in length. The growth in weight of the Fox Islands fish, however, was considered separately as these fish were consistently lighter than kiyis of corresponding length from other localities.

The Lake Michigan kiyi grows slowly, with the females growing slightly more rapidly than the males. The grand average calculated lengths indicated, for example, that the females did not attain a total length of 10 inches until the fifth year of life or the males until the sixth. Similarly, the calculated weight of 4 ounces was not reached until the fifth or sixth year (with the actual time varying with sex and locality). The season's growth of the kiyi probably begins sometime in May and most or all of the growth is completed by the end of August.

The calculated lengths of the age groups exhibited large discrepancies that differed from "Lee's phenomenon" as ordinarily observed in that the data for the later rather than the earlier years of life were affected most severely. Chief among the factors held responsible for these discrepancies were gear selection and the selective destruction of the more rapidly growing individuals in the fishery. Errors inherent in the (direct-proportion) method of computing growth from scale measurements were considered to have been unimportant. The Lake Michigan kiyi exhibits growth compensation—the tendency for the smaller of the young fish to have the more rapid growth in the later years of life.

Comparisons with the average lengths and weights of the age groups of the Lake Ontario kiyi given by Pritchard (1931) indicated the Lake Michigan fish to be the larger at the earlier ages (age-groups II and III) and the smaller at the later ages (age-groups IV to VI).

The length-frequency distributions of the age groups exhibited extensive overlap. As many as eight age groups were represented in a single centimeter interval of length. The length frequencies and average lengths of all fish collected, arranged according to the mesh sizes of the gill nets by which they were captured, revealed that the selective action of these nets in the taking of kiyis was much more obvious in the numbers of fish in the catch than in

their average size. As an illustration, in 1930-1931, the 2¾-inch mesh nets took fish that were only 0.1 inch longer than those in 2½-inch meshes but captured less than one fourth as many. Gill nets fished in northern Lake Michigan in 1932 captured kiyis that averaged 0.2 to 0.4 inch longer than those taken in the same meshes in southern Lake Michigan in 1930-1931.

Because of the more slender form of kiyis from the northeastern island region of Lake Michigan, data on the general length weight relationship were compiled separately for fish of that area and for those of the great central basins of the lake. In both regions the weight increased to a power slightly greater than the cube of the length. Available information on condition indicated that the coefficient (K) was higher in August and early September than in May, June, and July. Condition declined from early September to October and early November—the latter period the time of most active spawning. Spawning itself was accompanied by an additional loss of about 12 per cent of the body weight of females and of somewhat less than 2 per cent of the weight of males. Analysis of the variations of K within a group that was homogeneous with respect to age, sex, maturity, and time of collection revealed that a net of a particular mesh size tends to take the heavier of the shorter fish and the lighter of the longer fish within its range of effectiveness. Among fish of the same length the values of K tended to increase with increase in the mesh size of the nets employed for their capture.

Practically all fish in the samples were mature (only 11 immature in more than 6,000). These "immature" fish were probably "non-functional" since all of them approached or exceeded the average length of the mature kiyis.

Females were strongly predominant in the collections at all seasons but were relatively more plentiful during the summer (90 per cent of the total) than during the spawning period (75 per cent). Possible factors contributing to this predominance of females and to the change in the sex ratio at the spawning season were discussed. A decrease in the relative abundance of males with increase in age appears to be characteristic of the kiyi. This decrease indicates a differential mortality of th sexes (greater relative destruction of males in the spawning period when they are unusually abundant or a greater natural mortality rate for the males).

Current fishery regulations on mesh size and closed seasons afford the kiyi good protection but offer no guarantee against depletion from too intensive fishing.

Introduction

Except for the bloater, *L. hoyi*, the kiyi, *Leucichthys kiyi*, is the smallest of the seven known Great Lake species of chubs. In Lake Michigan, kiyis are generally abundant throughout the great central basins at depths of 40 or 50 fathoms down to at least 90 fathoms and are also taken frequently, albeit in small numbers, in shallower water. They are scarce, however, in the island region of northeastern Lake Michigan and have never been reported from Green Bay.

Because of its small size the kiyi was probably of little or no importance in the early commercial fishery of Lake Michigan. As the abundance of the larger, more valuable chubs declined, however, fishermen were forced to reduce the mesh size of their nets in order to take the smaller varieties. With this change of gear the kiyi entered the commercial catch and today makes up a substantial portion of the take

in some localities. The growing importance of the kiyi makes it desirable to have information on such phases of its natural history as distribution, size, age, growth, length-weight relationship, sex ratio, maturity, and spawning.

The kiyi was described originally from Lake Michigan (Koelz, 1921). A typical *kiyi* occurs also in Lake Superior and Lake Huron. The Ontario form, however, has been assigned to the subspecies *orientalis* (Koelz, 1929). Kiyis are absent from Lake Erie, which contains no chubs.

The one previous study of the growth of the species was made for the Lake Ontario kiyi by Pritchard (1931). For the Lake Michigan form the available published information has been limited to that contained in the two papers by Koelz, mentioned in the preceding paragraph. Koelz' 1929 publication included in addition to taxonomic data certain observations on the distribution, abundance, and breeding habits of the species. A rather comprehensive study by Hile and Deason (1947) of the bathymetric and geographical distrbiution, regional abundance, and spawning season and grounds of the Lake Michigan kiyi appears in the same volume with the present publication.

We wish to thank Dr. John Van Oosten, In Charge of Great Lakes Fishery Investigations, Fish and Wildlife Service, for his critical examination of the original manuscript and his excellent suggestions for its improvement. Dr. Frank W. Jobes of the Great Lakes Staff kindly prepared the three figures appearing in this paper.

Materials and Methods

Determinations of age and calculations of individual growth histories from the examination and measurement of scales were made for 1,649 kiyis collected by means of experimental chub gill nets[1] at seven localities and on eight dates (Table 1). The two samples from Port Washington have been treated in all analyses as a single collection. The fish taken out of Charlevoix will be designated the Fox Islands collection in later pages. The numbers of specimens used for certain other phases of the investigation were: Sex ratio—7,028; length-frequency distributions—6,625; relationship between total length and standard length—6,017; length-weight relationship—4,696.

All measurements and weights were taken in the field from fresh specimens. Measurements of length (total lengths were measured to the tip of the tail with the upper and lower edges parallel and standard lengths to the base of the caudal peduncle), which were recorded to the nearest millimeter, were made with a steel tape held as nearly parallel as possible to the long axis of the body. Lengths and incre-

[1]The experimental chub nets fished in Lake Michigan included the following mesh sizes (extension measure in inches as manufactured) in each standard gang: 1930 and 1931—2¾, 2½, 2⅝, 2¾, and 3; 1932—2½, 2⅝, and 2¾. See Deason (1932), Van Oosten (1933), and Hile and Deason (1947) for certain particulars relative to the participating organizations and the purposes and conduct of this experimental fishing.

ments of length presented in this paper in inches are total; those given in millimeters are standard. Weights were recorded to the nearest tenth (1931) or quarter (1930 and 1932) of an ounce.

TABLE 1.—*Location and date of capture of 1,649 Lake Michigan kiyis for which determinations of age and calculations of growth histories were made*

Port	Date	Course	Distance (miles)	Number of fish
Manistique, Mich.	June 14, 1932	SxW3/16W	30¾	202
Do.	July 9, 1932	SExE1/4E	21	125
Do.	Sept. 7, 1932	SSE5/16E	14¾	194
Charlevoix, Mich.[1]	Aug. 13, 1932	W1/8S	35	64
Kewaunee, Wis.	Oct. 15, 1931	ExS1/4S	11	313
Port Washington, Wis.	Aug. 13, 1931	ExN1/8N	16	495
Do.	Aug. 21, 1932			
Racine, Wis.	Oct. 9, 1931	ExN1/2N	22½	256

[1]Near the Fox Islands.

Scales for age and growth determinations were mounted on glass slides and examined by means of a microprojection apparatus at the magnification X 40.7. The diameters of the entire scale and of the growth field within each annulus were measured to the nearest millimeter. Computations of growth from scale measurements were made by direct proportion, that is, on the assumption that the ratio of body length to scale diameter is constant from the time of the formation of the first annulus. Although no data are available on the body-scale relationship of the kiyi, this method of calculation was proved to be satisfactory for the related species, *L. artedi* (Van Oosten, 1929).

Ages have been designated by roman numerals corresponding to the number of annuli or year marks on the scales. The term mature as employed here refers to fish that would have spawned at the next season, regardless of whether or not they had spawned previously.

AGE COMPOSITION

In the compilation of the data on the age composition of the samples of kiyi (Table 2) the sexes were combined for each locality, and the three 1932 collections from Manistique were treated as one. Males were generally so scarce (only 10.4 per cent of the grand total) that a separate presentation of the detailed data for the sexes in each collection did not seem to be justified. At the bottom of the table, however, has been given the age composition of males and females for all collections combined. The Manistique samples were combined because of the relatively small variations in the age composition from date to date.[2]

[2]The numerical representation of the fish of each sex in each age group of the various samples (including each of the individual Manistique collections) will be found in Tables 3 and 4. Questions concerning the relative abundance of males and females are considered in the section dealing with sex ratio.

TABLE 2.—*Numerical and percentage (in parentheses) representation of the age groups of kiyis from different localities in Lake Michigan and for all localities combined*

Locality	Age group								Total and average[1]
	II	III	IV	V	VI	VII	VIII	X	
Manistique	2 (0.4)	14 (2.7)	68 (13.0)	246 (47.2)	149 (28.6)	37 (7.1)	4 (0.8)	1 (0.2)	521 5.26
Fox Islands	....	2 (3.1)	17 (26.6)	29 (45.3)	12 (18.8)	4 (6.2)	....	....	64 4.98
Kewaunee	4 (1.3)	68 (21.8)	150 (47.9)	75 (23.9)	15 (4.8)	....	1 (0.3)	....	313 4.11
Port Washington	1 (0.2)	33 (6.7)	290 (58.6)	147 (29.7)	21 (4.2)	2 (0.4)	1 (0.2)	....	495 4.33
Racine	26 10.2)	74 (28.9)	115 (44.9)	33 (12.9)	6 (2.3)	2 (0.8)	....	....	256 3.71
All localities									
Male	7 (4.0)	37 (21.5)	71 (41.3)	44 (25.6)	11 (6.4)	2 (1.2)	....	....	172 4.12
Female	26 (1.8)	154 (10.4)	569 (38.5)	486 (32.5)	192 (13.0)	43 (2.9)	6 (0.4)	1 (0.1)	1,477 4.56
Both	33 (2.0)	191 (11.6)	640 (38.8)	530 (32.1)	203 (12.3)	45 (2.7)	6 (0.4)	1 (0.1)	1,649 4.51

[1]The second figure for each port or sex is the average number of annuli.

The outstanding feature of the data of Table 2 is the trend toward an increase in the average age of kiyis from south to north. The only exception to this trend was provided by the Kewaunee fish which averaged slightly younger than did those from Port Washington. At Racine, age-group IV was dominant (44.9 per cent) with age-group III second in abundance (28.9 per cent). The IV group was dominant at Port Washington (58.6 per cent) and Kewaunee (47.9 per cent) also. At both of these ports, however, V-group kiyis were more plentiful than were III-group fish. The dominance shifted to the V group in the Fox Islands sample (45.3 per cent) with age-group IV the next strongest. Finally, off Manistique age-group V was dominant (47.2 per cent) with the VI group second. These local differences in age composition resulted in a range in the average age from 3.71 at Racine to 5.26 at Manistique.

Age-group IV was dominant (38.8 per cent) in the combined collections. The V group was only slightly less abundant (32.1 per cent) and was between two and three times as well represented as either age-group VI (12.3 per cent) or age-group III (11.6 per cent). Other groups were represented only sparsely (0.1 to 2.7 per cent). The comparison of the data for the sexes reveals that the younger age groups (II to IV) were relatively better represented while the older age groups (V and older) were more poorly represented among the males than among the females. The average ages of the sexes were: Males—4.12; females—4.56.

Some of the local differences in age composition and average age are sufficiently large to be taken as indicative of real differences among the samples. The possible effects of certain distorting factors must be considered, however, before these variations can be discussed in terms of real differences among the kiyi stocks of the several regions.

A possible major source of distortion lay in the change of gear from nets of five mesh sizes in 1930 and 1931 (no scale collections in the former year) to nets of three mesh sizes in 1932 (see footnote 1). The omission of the 2⅜ mesh in 1932 (the year of collection of the Fox Islands and Manistique samples) could have been extremely damaging since nets of that mesh size were the most successful of the five employed in earlier years for the capture of kiyis (Table 6). In order to estimate the effects of the change in gear, the average ages were determined of the kiyis taken off Racine, Port Washington, and Kewaunee in nets of the same three mesh sizes that were fished in 1932 (that is, the samples from the 2⅜- and 3-inch-mesh nets were excluded). Comparisons of the average ages of fish from nets of five and of three mesh sizes appear below (numbers of fish in parentheses):

	Average age of kiyis	
Port	*From five mesh sizes*	*From three mesh sizes*
Kewaunee	4.11 (313)	4.36 (196)
Port Washington	4.33 (495)	4.43 (275)
Racine	3.71 (256)	3.40 (144)

The ages of kiyis from nets of the three mesh sizes averaged slightly higher than did those of fish from nets of five mesh sizes in both the Kewaunee and Port Washington samples. At Racine, however, the kiyis from three nets averaged somewhat younger than did those from five. Because the differences between the average ages of fish from the two groups of nets were not large or consistent as to direction, it may be concluded that the change in gear from 1931 to 1932 is not a distorting factor in the observed differences in age composition and average age of the fish taken in the two years.

Since males usually averaged younger than females of the same collection, and since the Kewaunee and Racine samples were taken during the spawning period, at which time males ordinarily are relatively more plentiful than in other seasons (p. 133), the possible effects of the greater relative abundance of males in these two collections on the determination of the average age was investigated. Computations revealed that had the percentages of males and females in the Kewaunee collection been the same as in the August samples from

Port Washington the average age of the Kawaunee fish (sexes combined) would have been 4.13 rather than 4.11. In the Racine samples where the average age of the males, contrary to the usual situation, was greater than that of the females, a similar reduction in the representation of the males would have reduced the average for the combined sexes from 3.71 to 3.69. It was impossible to demonstrate, therefore, that the greater abundance of males in the spawning-run samples affected significantly the average age.

Local differences in growth rate in combination with the selection of fish according to size by the gill nets offer a third possible source of distortion. As a gill net of a particular mesh tends to take fish over a relatively limited range of size, the individuals from slowly growing stocks might be expected to average older than those from populations with rapid growth. It will be brought out in the next section, however, that aside from the tendency of kiyis of northeastern Lake Michigan to be lighter (but not shorter) than fish of corresponding age from other localities the local variations in the growth of the Lake Michigan kiyi were small. The fish of the Fox Islands sample possibly might have had a slightly lower average age had they been less slender. There is no other evidence for local differences in growth rate that could be expected to affect the age composition of the samples.

Since the apparently most probable sources of bias were demonstrated to have had no important effect on the data of Table 2, it may be concluded that the observed local variations in age composition represented, in the main, real differences among the populations from which the samples were drawn.

It is possible that a progressive south-to-north increase in the natural life span of the kiyi may have contributed to the local fluctuations in age composition. It is conceivable also that differences between the average ages in 1931 (Racine, Port Washington, and Kewaunee collections) and in 1932 (Fox Islands and Manistique collections) were in part the result of an exceptionally strong 1927 year class that was dominant as the IV group in 1931 and as the V group in 1932. On the other hand, some of the variation—notably the differences between the northern (State of Michigan) and southern (State of Wisconsin) samples—can be explained logically as the result of differences in the intensity of the fishery and consequently in the mortality rate.

Although information on the amount of gear lifted is lacking for Wisconsin waters previous to 1936[3] and hence no exact comparison can be made with Michigan data, it is well known that at the time of the chub-net investigations the fishery for chubs was far more intensive in the Wisconsin waters than in the Michigan waters of Lake Michigan. The inequality in fishing pressure was doubtless much greater for the kiyi in particular than for chubs in general, because of dif-

[3] Records of the amount of all types of gear lifted, beginning with 1929, are available in the files of the Great Lakes laboratory of the Fish and Wildlife Service for the State of Michigan waters of the Great Lakes.

ferences in the mesh size of commercial shub nets in the two states. For some time before and during the years of the experimental fishing the minimum legal mesh size for chub nets in the State of Michigan waters was 2¾ inches (extension measure). This regulation was reasonably well enforced. In Wisconsin the minimum legal mesh size for chub nets was 2⅝ inches, but so many fishermen used a smaller mesh that the true average difference between the meshes in Michigan and Wisconsin waters was without doubt substantially greater than the indicated one-eighth inch. Since the kiyi is a small, slowly growing chub the nets of Wisconsin fishermen must have been much more effective for its capture than were the larger-meshed nets of the Michigan operators.

At first thought, the suggestion that the higher average age of kiyi from northern Lake Michigan was the result of a lower fishing intensity would appear to conflict with the statement by Hile and Deason (1947) to the effect that Wisconsin and Michigan fishermen probably exploit the same stocks of the species. That statement referred, however, to southern Lake Michigan waters (near and south of the Kewaunee-Frankfort line). The more northerly grounds from which the Manistique and Fox Islands samples were collected were rather remote from the chief centers of the Wisconsin fishery and therefore these kiyis may have been drawn from stocks that were subject to little or no exploitation by Wisconsin operators. It is known also that in the State of Michigan waters the intensity of the chub fishery in the northerly region was generally less than toward the south. Furthermore, the intensity of the chub fishery of the Manistique and northeastern areas in both 1931 and 1932 (1930 also off Manistique) was below the 1929-1943 average.[4] The combined effects of larger mesh in Michigan chub nets and the low fishing intensity in northern Lake Michigan may have permitted the kiyis of that region to survive to a greater average age than did the fish of more southerly waters.

The data given by Hile and Deason (1947) on the abundance of kiyis yielded no evidence for an accumulated stock in the northern waters, since the abundance was apparently about the same in the Manistique region as in southern Lake Michigan, and kiyis were scarce at localities in the northeastern island region. It should be remembered, however, that general ecological conditions doubtless vary in these widely separated regions, and hence that with respect to the natural carrying capacity, a population density that is sparse for one area may represent an accumulated stock for another.

Length and Weight at Capture; Length-Frequency Distributions

Some of the variations in the average length and weight of kiyis of corresponding age and sex of the different collections (Tables 3 and 4) doubtless represent true differences among the samples. The extent to

[4]This statement is based on records of the actual quantity of gear lifted.

which these variations indicate real differences in the normal growth rate of kiyis in the several regions of the lake, however, is difficult to decide. Comparisons of the average size of the fish in the corresponding age groups in different collections should include consideration of certain sources of variability not related at all to the true rate of growth.

It may be pointed out first that comparisons of length are more reliable than comparisons of weight. Seasonal and annual fluctuations in condition are sufficiently great (p. 122) to bring about rather large variations in average weight that are independent of length.[5]

The time of capture during the growing season doubtless affected some of the averages of Tables 3 and 4. In the Manistique collections the size of the female kiyis (males were extremely scarce in these samples) of every age group increased from June 14 to July 9. The averages for the September collection indicated some increase in weight after July but did not show an increase in length (increase in one age group; decrease in two age groups; no change in two age groups).[6] The Fox Islands and Port Washington averages also might have been slightly greater had the collections been made later in the season, although the data of a later section (p. 120) suggest that the increase in size after mid-August probably would not have been large.

The effects of gill-net selection also should be considered in the comparison of the average size of the fish. Cognizance should be taken particularly of the fact that gill nets of a greater range of mesh size (five sizes) were employed in 1931 than in 1932 (three sizes). In order to estimate the probable effects of this change in gear the average lengths and weights of the three best represented age groups (III, IV, and V) of female kiyis in the three 1931 collections were determined with the samples from the 2⅜- and 3-inch-mesh nets excluded. Of the nine age groups involved, two showed no increase in length over the average for fish from five nets, four showed an increase of 0.1 inch, and three an increase of 0.2 inch. All nine age groups exhibited an increase in average weight ranging from 0.05 to 0.43 ounce and averaging 0.27 ounce. It appears, then, that the age groups of the 1931 collections would have averaged slightly larger had the same gear been used in that year as in 1932. Conversely, it would be expected that the age groups of the Manistique and Fox Islands collections would have had somewhat lower average lengths and weights had nets of five rather than three mesh sizes been employed for their capture.

Even without change of gear, gill-net selection can be of importance since variations in condition or relative heaviness can affect the

[5]The weights of the kiyis of the Fox Islands collection require special consideration (p. 124).

[6]It will be shown later from the calculated increments of length for the 1932 season that a certain amount of growth in length did occur after July 9, but that this growth was obscured in the comparisons of the average sizes at capture in July and September by the fact that the sample of the latter month was made up of fish that had made slower past growth than had the kiyis of the July collection (p. 118).

TABLE 3.—*Average total length (inches) and weight (ounces) of male kiyis of each age group in the various collections from Lake Michigan*

[The averages at the bottom of the table include also the standard lengths in millimeters and the weights in grams]

Locality and date	Item	Age group						Average or total
		II	III	IV	V	VI	VII	
Manistique (June 14, 1932)	Total length....	7.0	.....	10.5	9.8	9.8	11.2	9.9
	Weight	1.50	.....	5.00	4.00	4.00	6.50	4.31
	Number of fish	1	.....	4	6	1	1	13
Manistique (July 9, 1932)	Total length....	.....	.....	8.9	11.3	10.2	.....	10.2
	Weight	.....	.....	3.25	6.25	4.38	.....	4.56
	Number of fish	.....	.....	1	1	2	.....	4
Manistique (Sept. 7, 1932)	Total length....	.....	.....	10.6	10.8	10.4	.....	10.6
	Weight	.....	.....	6.00	6.15	5.50	.....	5.92
	Number of fish	.....	.....	1	5	3	.....	9
Fox Islands (Aug. 13, 1932)	Total length....	.....	7.6	9.8	10.2	10.3	.....	9.8
	Weight	.....	2.00	4.00	4.50	4.62	.....	4.09
	Number of fish	.....	1	2	3	2	.....	8
Kewaunee (Oct. 15, 1931)	Total length....	8.9	9.7	10.1	10.1	10.9	.....	9.9
	Weight	3.40	4.30	4.60	4.91	6.20	.....	4.57
	Number of fish	1	19	20	12	1	.....	53
Port Washington (Aug. 13 and 21, 1931)	Total length....	9.7	9.2	9.9	10.3	11.5	.....	9.9
	Weight	4.20	3.73	4.90	5.20	7.90	.....	4.85
	Number of fish	1	6	23	9	1	.....	40
Racine (Oct. 9, 1931)	Total length....	10.2	10.4	10.5	10.6	10.3	10.1	10.5
	Weight	4.70	5.19	5.00	5.02	4.60	5.50	5.03
	Number of fish	4	11	20	8	1	1	45
All collections except from Manistique in June and from the Fox Islands	Total length....	9.9	9.8	10.1	10.4	10.5	10.1	10.1
	Weight	4.40	4.48	4.83	5.23	5.50	5.50	4.86
	Standard length	208	205	214	218	223	211	213
	Weight (grams)	125	127	137	148	156	156	138
	Number of fish	6	36	65	35	8	1	151

TABLE 4.—*Average total length (inches) and weight (ounces) of the female kiyis of each age group in the various collections from Lake Michigan*

[The averages at the bottom of the table include also the standard lengths in millimeters and the weights in grams]

Locality and date	Item	Age group								Average or total
		II	III	IV	V	VI	VII	VIII	X	
Manistique (June 14, 1932)	Total length	.....	9.3	10.2	10.7	10.9	11.0	10.8	.....	10.7
	Weight	.....	3.60	4.74	5.56	6.04	6.00	6.00	.....	5.57
	Number of fish	.....	5	23	98	54	8	1	.....	189
Manistique (July 9, 1932)	Total length	10.0	10.0	10.5	10.9	11.1	11.1	.....	.....	10.9
	Weight	4.50	4.68	5.01	5.94	6.20	6.03	.....	.....	5.79
	Number of fish	1	7	19	47	32	15	.....	.....	121
Manistique (Sept. 7, 1932)	Total length	.....	10.8	10.5	10.6	11.0	11.1	11.4	10.6	10.8
	Weight	.....	5.75	5.91	5.96	6.58	6.85	7.58	5.75	6.23
	Number of fish	.....	2	20	89	57	13	3	1	185
Fox Islands (Aug. 13, 1932)	Total length	.....	9.9	10.6	10.9	11.1	11.3	.....	.....	10.9
	Weight	.....	2.75	4.82	5.60	5.80	5.69	.....	.....	5.38
	Number of fish	.....	1	15	26	10	4	.....	.....	56
Kewaunee (Oct. 15, 1931)	Total length	9.7	9.8	10.3	10.7	10.7	.....	10.6	.....	10.3
	Weight	4.58	4.47	5.33	5.78	6.32	.....	5.75	.....	5.32
	Number of fish	3	49	130	63	14	.....	1	.....	260
Port Washington (Aug. 13 and 21, 1931)	Total length	.....	9.8	10.3	10.7	10.8	11.5	12.4	.....	10.4
	Weight	.....	4.80	5.42	5.97	6.17	7.10	8.75	.....	5.60
	Number of fish	.....	27	267	138	20	2	1	.....	455
Racine (Oct. 9, 1931)	Total length	10.2	10.5	10.9	10.9	10.5	11.9	.....	.....	10.7
	Weight	5.11	5.68	5.99	6.05	5.20	7.40	.....	.....	5.80
	Number of fish	22	63	95	25	5	1	.....	.....	211
All collections except from Manistique in June and from the Fox Islands	Total length	10.1	10.1	10.4	10.7	10.9	11.2	11.4	10.6	10.5
	Weight	5.03	5.07	5.50	5.94	6.34	6.49	7.45	5.75	5.69
	Standard length	213	212	218	225	230	234	241	228	221
	Weight (grams)	143	144	156	168	180	184	211	163	161
	Number of fish	26	148	531	362	128	31	5	1	1,232

average length of the fish captured. Selection on this basis is believed, for example, to account for the fact that the best represented age groups (IV to VII) of the females of the Manistique collection of September had average lengths that were the same or less than those of fish of the same ages in the July collection. The weight of the fish increased in every age group, and the calculated increments (p. 118) indicated that growth in length did take place after July 9. The gill nets simply took the shorter of the relatively plump September fish. The average lengths of the kiyis of other age groups doubtless were affected by the condition of the fish on the grounds at the time of capture. (See pp. 128-133 for data and discussion on the effect of gill-net selection on the estimation of the average value of the coefficient of condition.)

The selective destruction of the more rapidly growing individuals in the fishery offers another important source of differences in the average size of fish of the same age in the various samples. The more intensive the fishery the more likely are the individuals with rapid growth to be captured at an early age. Samples drawn from the residual stock of slow growers will yield averages that are too low in comparison with the true growth rate. The effects of this selection will vary, of course, with local variations in fishing pressure. The destruction of the rapidly growing individuals in the fishery very probably contributed to the low average size of the kivis of the Kewaunee and Port Washington samples since the exploitation of shubs is known to have been particularly heavy in those regions of Lake Michigan.

The sources of selection and of distortion of the data just outlined seem to be adequate to explain most of the variations in the average lengths and weights of the age groups in the different collections. Although some real local differences in growth rate may exist, it is believed that the only demonstrable regional difference is provided by the growth in weight of the kiyis of the Fox Islands collection, in which the average weights of the age groups were rather consistently low. The weight of the IV-group females, for example, was less in the Fox Islands sample than in any other collection except the one taken off Manistique on June 14, and these Manistique fish averaged the shorter by 0.4 inch. Furthermore, the average weight of the Fox Islands IV group was less than that of four other samples of IV-group females with lower average lengths. A similar situation held for the other age groups of the Fox Islands kiyis. The slow growth in weight of the Fox Islands fish is the result of differences between the length-weight relationships of kiyis from the island region of northeastern Lake Michigan and from the central basins of the lake (p. 124). Growth in length was much the same at the Fox Islands as elsewhere in Lake Michigan.

If the June 14 sample from Manistique is excluded because of its collection early in the growing season and the Fox Islands fish are omitted because of the slow growth in weight, the data for the re-

maining collections may be combined to obtain an estimate of the general relationship between the age and size of kiyis captured late in the growing season (see bottoms of Tables 3 and 4). Attention may be given first to the data for the females since fish of that sex formed the bulk of the collections.

The differences among the average lengths and weights of the age groups of female kiyis were in general small. Although an increase in both length and weight did occur in every age group from IV to VIII, the length increments were only 0.2 or 0.3 inch (4 to 7 millimeters) and the weight increments were only 0.15 to 0.96 ounce (4 to 27 grams). Age-groups III and X provided exceptions to the increase in size with increase in age. The almost identical averages for age-groups II and III can be considered the result of gill-net selection; the scarcity of II-group fish indicates that only the larger members of the age group were captured. (The fact that III-group females were much less numerous than IV-group females suggests that the averages for the III group also may have been too high.) No significance can be attached to the low figures of length and weight of age-group X since that age was represented by only one fish.

The grand average length of all females (exclusive of the Manistique collection in June and the Fox Islands collection) was 10.5 inches (221 millimeters) and the grand average weight was 5.69 ounces (161 grams).

The data for the males resembled those for the females in that age-groups II and III exhibited only small differences, and the averages for the later age groups showed a slow but steady increase in length and weight with the exception of the oldest age group (VII) which was represented by only one individual. The length increments of the age groups that showed an increase in size ranged from 10.1 to 0.3 inch (4 to 9 millimeters) and the weight increments from 0.27 to 0.40 ounce (8 to 11 grams).

Females averaged longer and heavier than males of the same age. In the best represented age groups the length advantage of the females was 0.3 inch (age-groups III, IV, and V) or 0.4 inch (age-group VI). The weight advantage of the females increased regularly from 0.59 ounce in the III group to 0.84 ounce in the VI group. For all age groups combined the average length of the males was 0.1 inches (0.4 inch less than the average for the females) or 213 millimeters. The grand average weight was 4.86 ounces (0.83 ounce less than the average for the females) or 138 grams.

The small differences among the average sizes of the fish of the several age groups are brought out forcibly by the length-frequency distributions of kiyis of the late-season collections[7] (Table 5). It is true that in age-groups IV to VIII the increases in the average length

[7]The Fox Islands collection, which was excluded in the computation of the averages at the bottom of Tables 3 and 4 because of the low average weights of the age groups, was employed in the preparation of the length-frequency tabulations since apparently the growth in length in the Fox Islands region was similar to that in other areas.

TABLE 5.—*Length frequencies of the age groups of kiyis, with the data combined for all collections, except the June collection from Manistique*

[The total lengths in the second column are equivalent to the midpoints of the intervals of standard length. M = male; F = female]

Standard length, millimeters	Total length, inches	Age group														Totals for sexes		Grand total	Percentage
		II		III		IV		V		VI		VII		VIII	X				
		M	F	M	F	M	F	M	F	M	F	M	F	F	F	M	F		
150-159....	7.4	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	1	0.1
170-179....	8.3	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	1	0.1
180-189....	8.8	.....	.....	2	1	1	1	.....	1	.....	.....	.....	.....	.....	.....	3	3	6	0.4
190-199....	9.3	2	2	7	17	5	10	3	2	1	.....	.....	1	.....	.....	18	32	50	3.4
200-209....	9.8	2	6	13	49	16	88	9	17	2	6	.....	.....	.....	.....	42	166	208	14.4
210-219....	10.3	1	11	8	37	29	208	12	79	.....	16	1	4	.....	.....	51	355	406	28.0
220-229....	10.7	1	7	6	34	14	157	5	156	3	41	.....	7	1	1	29	404	433	29.9
230-239....	11.1	.....	.....	.....	5	2	54	6	107	3	46	.....	6	2	.....	11	220	231	16.0
240-249....	11.6	.....	.....	.....	5	.....	26	2	21	1	22	.....	14	.....	.....	3	88	91	6.3
250-259....	12.1	.....	.....	.....	1	.....	1	1	5	.....	7	.....	3	1	.....	1	18	19	1.3
260-269....	12.6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	1	1	0.1
Total		6	26	37	149	67	546	38	388	10	138	1	35	5	1	159	1,288	1,447	.....
Aver. total length..		9.9	10.1	9.7	10.1	10.1	10.4	10.4	10.7	10.5	10.9	10.1	11.2	11.4	10.6	10.1	10.5	10.5	.....
Aver. stand. length		208	213	204	212	214	218	218	225	222	230	211	234	241	228	213	221	220	.....

of the females were accompanied by 1-centimeter increases in the modal length. (Among the weakly represented males the position of the mode varied irregularly.) Nevertheless, the overlap of the frequency distributions of the age groups was generally so great that the length of kiyis must be considered a very poor index of the age. Especialy striking is the situation at 220-229 millimeters at which interval were represented all of the eight age groups of females and five of the six age groups of males present in the samples. Similar though less extreme overlapping of age groups occurred at other length intervals in which fish were abundant.

The distribution for the combined age groups were remarkably compact in spite of the fact that gill nets of three or five mesh sizes were used for the collection of the samples. One hundred twenty-two or 76.7 per cent of the males were within the interval, 9.6-10.9 inches (200-229 millimeters), and 979 or 76.0 per cent of the females fell within the range, 10.1-11.4 inches (210-239 millimeters). In the distribution for the sexes combined 58.0 per cent of the fish were included in the interval, 10.1-10.9 inches (210-229 millimeters), and 88.3 per cent were from 9.6 inches (200 millimeters) to 11.4 inches (239 millimeters) long.

More detailed information on the length-frequency distribution and average size of kiyis, especially as related to the size of mesh of gill nets, may be found in Table 6. In order to present the frequencies in a table of reasonable size the data for the sexes have been combined, although where the samples were large the males averaged smaller and had lower modal lengths than did the females. These sex differences were much the same as those to be observed in the totals at the right of Table 5. The combination of data for the sexes should not affect the comparison of figures for nets of different mesh since males were generally scarce and no clear-cut or consistent relationship could be found between mesh size and the sex ratio (p. —).

It should be mentioned also that the frequencies were not based on actual measurements of all the fish listed but were estimated by the application of the percentage-frequency distributions as determined from samples from nets of the various mesh sizes to the corresponding total numbers of kiyis captured in lifts in which the fish were identified from nets of all (5 or 3) mesh sizes.[8] This procedure was made desirable by the variation in the percentage of fish measured from the total catch of nets of different mesh size (for example, a smaller percentage was measured from fish taken by the 2⅜-inch-mesh nets than from the catch of nets of any other mesh). In the following discussion the data for the five-net gangs of 1930-1931 will be treated first.

In spite of the rather large total ranges of length of kiyis in the gill

[8]Numbers of fish actually measured are shown in the second row of the bottom section of the table. In some of the largest lifts it was necessary to restrict the identification of chubs to a sample. For these lifts the total number in the catch from a particular mesh size was estimated by multiplying the number of kiyis in the sample by the ratio of the number of chubs in the total lift to the number in the sample.

TABLE 6.—*Length frequencies of all kiyis captured and identified from Lake Michigan, 1930-1932*

[The frequencies were computed from the distributions of samples of measured fish. The total lengths in the second column are equivalent to the midpoints of the intervals of standard length. The gill-net meshes are extension measure in inches as manufactured]

Standard length (millimeters)	Total length (inches)	Gill-net mesh in 1930-1931							Gill-net mesh in 1932				
		2⅜	2½	2⅝	2¾	3	Total	Percentage	2½	2⅝	2¾	Total	Percentage
140-149	6.9	.....	3	.....	.....	2	5	[1]0.0	.....	2	.....	2	0.1
150-159	7.4	.....	.....	.....	.....	.....	.....	.....	2	.....	.....	2	0.1
160-169	7.9	9	.....	2	2	4	17	0.1	.....	2	.....	2	0.1
170-179	8.4	19	3	5	6	12	45	0.3	3	3	.....	6	0.2
180-189	8.8	65	23	25	18	17	148	1.0	4	3	2	9	0.3
190-199	9.3	537	95	49	44	57	782	5.2	30	25	16	71	2.7
200-209	9.8	2,307	400	199	69	65	3,040	20.3	85	36	28	149	5.6
210-219	10.3	3,326	1,014	360	107	29	4,836	32.3	282	92	30	404	15.2
220-229	10.7	2,168	1,070	458	157	21	3,874	25.9	571	244	70	885	33.4
230-239	11.2	667	486	301	145	9	1,608	10.8	361	250	82	693	26.2
240-249	11.6	148	141	122	64	9	484	3.3	130	127	66	323	12.2
250-259	12.1	19	40	20	23	2	104	0.7	26	31	30	87	3.3
260-269	12.6	.....	3	5	.....	4	12	0.1	2	3	4	9	0.3
270-279	13.1	.....	3	.....	.....	4	7	[1]0.0	2	.....	2	4	0.2
280-289	13.5	.....	.....	.....	2	.....	2	[1]0.0	2	.....	.....	2	0.1
Total		9,265	3,281	1,546	637	235	14,964	.....	1,500	818	330	2,648	.....
Number measured		2,556	1,361	773	321	112	5,123	.....	864	453	185	1,502	.....
Average total length		10.3	10.5	10.5	10.6	9.9	10.4	.....	10.7	10.9	10.9	10.8	.....
Average standard length		214	220	221	222	206	217	.....	224	228	230	226	.....

[1]Less than 0.05.

nets of the five mesh sizes fished in 1930-1931, the ranges over which fish were taken in abundance were relatively small. Computations of percentage frequencies for the individual nets will show, for example, that the modal centimeter (½-inch[9]) interval contained from 35.9 per cent (2⅜-inch mesh) to 24.6 per cent (2¾-inch mesh) of the total numbers of kiyis captured. Furthermore, the best represented 3-centimeter (1.4-inch) interval included from 84.2 per cent (2⅜-inch mesh) to 64.2 per cent (2¾-inch mesh) of the total.

The variations among the average lengths of kiyis from nets of different mesh size were surprisingly small. The increase of mesh size from 2⅜ to 2½ inches was accompanied by a 6-millimeter (0.2-inch) rise in the average length. The mode also shifted 10 millimeters (from 210-219 millimeters to 220-229 millimeters). The differences among the 2½-, 2⅝-, and 2¾-inch meshes, however, were unimportant. The modal lengths were the same for all three nets (220-229 millimeters) and the maximum variation among the average lengths was only 2 millimeters (0.1 inch). The net with the largest mesh (3 inches) took the kiyis with the lowest modal (200-209 millimeters) and average (206 millimeters; 9.9 inches) lengths. This odd situation is the result of the capture of numbers of small individuals (termed "snipes" by the commercial fishermen) that were not gilled but were held by the mouth parts that had become entangled in the webbing.

Where the average and modal lengths varied but little, the numbers of kivis captured by the chub gill nets decreased rapidly with increase in the size of the mesh (⅛-inch increases except the 3-inch mesh which was ¼ inch larger than the next smaller size). These decreases, expressed as percentages, were found to range from 64.6 per cent (from 2⅜- to 2½-inch meshes) to 52.9 per cent (from 2½- to 2⅝-inch meshes). Particularly noteworthy are the comparisons among the three intermediate mesh sizes. The 2½-inch-mesh nets took kivis that were only 1 millimeter shorter than those captured by the 2⅝-inch-mesh nets (difference in total length is nil when expressed to the nearest 0.1 inch) but took 2.1 times as many individuals. The average lengths of kiyis from the 2⅝- and 2¾-inch-mesh nets exhibited a similar difference (1 millimeter; 0.1 inch) but the former net captured 2.4 times as many fish as the latter. Finally, the 2½-inch-mesh nets held 5.2 times as many kiyis as the 2¾-inch-mesh nets although the difference between the average lengths was only 2 millimeters (0.1 inch).

For the mesh sizes fished and for the stock of kiyis available in 1930 and 1931, therefore, the effect of gill-net selection was much more evident in the numbers of fish taken than in the sizes of individuals in the samples. In the combined samples of the nets of all five mesh sizes as in the collections from the individual meshes the bulk of the kiyis fell within a rather limited range of length. The modal-

[9]One centimeter of standard length corresponds to approximately 0.48 inch of total length—see page 107.

(half-inch) interval of 210-219 millimeters (equivalent midpoint, 10.3 inches) included 32.3 per cent of the total number of kiyis captured; 78.5 per cent of the total fell within the interval. 9.6-10.9 inches (200-229 millimeters). The grand average length of all kiyis captured in 1930-1931 was 10.4 inches (217 millimeters).

Comparisons of the 1932 data for northern Lake Michigan with the 1930-1931 data for southern Lake Michigan indicate a greater relative abundance of the larger kiyis in the northern area. It may be pointed out first that in 1932 the average lengths of the kiyis were consistently greater (4 to 8 millimeters; 0.2 to 0.4 inch) than those of fish captured by gill nets of corresponding mesh size in 1930-1931. Second, the length distribution of kiyis on the grounds was such as to permit successive increases of 4 and 2 millimeters (0.2 and 0.0 inch[10]) in average length with increase in mesh size as compared with corresponding rises of only 1 millimeter in 1930-1931. The increase in length of fish from the 2⅝-inch mesh over that of fish from the 2½-inch mesh was sufficiently great to involve a shifting of the mode from 220-229 millimeters to 230-239 millimeters. The mode remained at the latter interval, however, in the distribution of the kiyis from the 2¾-inch-mesh nets (possibly because of a scarcity of fish of sizes that could be taken most readily in these nets).

In northern Lake Michigan as in southern Lake Michigan the numbers of kiyis captured decreased sharply with increase in mesh size. The data for the northern region agree further with those of the southern in that the frequency distribution of the combined samples from nets of all mesh sizes fished was compact. More than one-third (33.4 per cent) of the total number of fish fell in the modal interval (220-229 millimeters; equivalent midpoint, 10.7 inches), and 74.8 per cent came within the length range of 10.1-11.4 inches (210-239 millimeters). The grand average length of all kiyis captured was 10.8 inches (226 millimeters). This average was 0.4 inch (9 millimeters) greater than that for kiyis from nets of five mesh sizes in 1930-1931 and 0.3 inch (5 milimeters) greater than the average for 1930-1931 samples from the same three mesh sizes fished in 1932.

The largest kiyi (longest and heaviest) measured was a spent male that was 13.8 inches (287 millimeters) long and weighed 11.7 ounces (332 grams). This fish was captured off Kewaunee, Wisconsin, on November 5, 1931. The largest female, a ripe fish which was taken off Racine, Wisconsin, on October 30, 1931, was nearly as heavy (11.6 ounces; 329 grams) but was shorter (13.2 inches; 277 millimeters). Both of these fish were well above the maximum size reported for the Lake Michigan kiyi by Koelz (1929) who stated, "Extreme examples selected from hundreds of specimens in the field measure only 245 millimeters [standard length; 11.7 inches total length]."

The total lengths given in this paper other than the average lengths

[10]The total lengths corresponding to standard lengths of 228 and 230 millimeters are slightly more than 10.85 inches and slightly less than 10.95 inches respectively.

for age groups at capture and lengths of individual fish were computed by means of conversion factors determined from the measurements of the total and standard lengths of 6,017 kiyis. These factors for the conversion of standard lengths in millimeters to total lengths in inches were: 0.0479 for standard lengths up to 220 millimeters; 0.0476 for standard lengths of 220 millimeters or greater.

Comparison of the Growth of the Kiyi in Lakes Michigan and Ontario

Average lengths and weights of age-groups II to VI of the Lake Ontario kiyi given by Pritchard (1931) permit a comparison of the growth of the species in two of the Great Lakes (Table 7). Since Pritchard made no separation of the data for the sexes, the lengths and weights of the males and females have been combined to obtain the averages given in the table for the age groups of the Lake Michigan kiyi. Only standard lengths have been presented as the total lengths of the Lake Ontario fish were measured to the fork of the tail while those of the Lake Michigan kiyis were measured to the extreme tip of the tail (with the upper and lower edges parallel). The younger age groups of the Lake Michigan kiyi (II and III) averaged larger and the older age groups (IV to VI) averaged smaller than fish of corresponding age from Lake Ontario. According to these figures, therefore, the Lake Michigan kiyis grew the more rapidly in the early years of life and the Lake Ontario kiyis had the better growth in the later years.

Table 7.—*Comparison of the average standard lengths and weights of the age groups of kiyis in Lake Michigan and Lake Ontario*

[The data for the Lake Ontario kiyis are from Pritchard (1931)]

	Lake Michigan		Lake Ontario	
Age group	Length (millimeters)	Weight (grams)	Length (millimeters)	Weight (grams)
II	210	137	178	82
III	211	139	203	125
IV	218	153	222	167
V	224	164	241	207
VI	229	175	274	302

Several circumstances throw doubt on the data of Table 7 as a reliable measure of differences in the growth rates of the kiyis in the two lakes. First may be mentioned differences in the experimental gear employed. Seventy per cent of the 524 kiyis captured in experimental gill nets in Lake Ontario were taken in meshes that were smaller (four mesh sizes from 1¼ to 2¼ inches) than any fished in Lake Michigan (five mesh sizes from 2⅜ to 3 inches). The three mesh sizes (2½, 2¾, and 3 inches) that were fished in Lake Ontario and that came within the range fished in Lake Michigan took 25.6 per cent of the kiyis, while nets of five larger mesh sizes (3½ to 5 inches) captured the remaining 4.4 per cent. It seems likely that Pritchard's samples had the better representation of the smaller fish and hence

of the younger age groups. That the representation of the larger fish (in relation to the population present) was much better in the Ontario than in the Michigan samples seems doubtful in view of the small numbers of individuals from the Ontario nets with mesh sizes greater than those of nets fished in Lake Michigan (most probably a considerable proportion of the kiyis from the largest meshes fished by Pritchard were "accidental" captures of fish held by their mouth parts) and of the evidence of the preceding section that the Michigan nets could have taken longer fish had they been available.

Attention should be called also to the extremely intensive fishery in Lake Michigan that tended to eliminate the individuals with the more rapid growth and hence to cause the samples of the successively older age groups to include an increasing percentage of individuals with growth rates below the normal (p. 100).

Differences in the growth rates of the sexes together with differences in the sex ratio in the two lakes may account for some of the discrepancies.

Finally, part of the disagreements may be the result of the inadequate numerical representation of certain age groups. (Pritchard did not give the numbers of specimens upon which the averages for the age groups were based—see Table 2 for the numbers in the age groups of the Lake Michigan kiyi.)

From the preceding considerations it seems likely that the differences between the growth of the kiyi in Lake Michigan and in Lake Ontario may not be as great as would appear from the data of Table 7. It is particularly significant that the best agreement is to be found in the data for age-group IV which was probably one of the most adequately represented groups in the Lake Michigan collections.

Calculated Growth in Length and Weight

Growth of the age groups and general growth in length.—The combination of the data for all collections to obtain the growth histories of the age groups and the general growth for all age groups combined (Tables 8 and 9) was made only after careful comparisons of the data

Table 8.—*Calculated lengths of each age group of male kiyis and grand average calculated lengths*

[The data for all collections have been combined]

Age group	Number of fish	Calculated standard length (millimeters) at end of year of life						
		1	2	3	4	5	6	7
II	7	112	171	.....	.....	.....	.....	.....
III	37	99	144	179	.....	.....	.....	.....
IV	71	101	143	174	197	.....	.....	.....
V	44	97	136	166	186	202	.....	.....
VI	11	96	137	163	180	197	211	.....
VII	2	94	136	168	189	202	210	221
Average		100	142	172	192	201	211	221
Increment		100	42	30	20	9	10	10
Total length (inches)		4.8	6.8	8.2	9.2	9.6	10.1	10.5
Increment		4.8	2.0	1.4	1.0	0.4	0.5	0.4
Number of fish		172	172	165	128	57	13	2

TABLE 9.—*Calculated lengths of each age group of female kiyis and grand average calculated lengths*

[The data for all collections have been combined]

Age group	Number of fish	Calculated standard length (millimeters) at end of year of life								
		1	2	3	4	5	6	7	8	9	10
II	26	113	175	.....	.....	.....	.....	.....	.....	.....	.....
III	154	103	147	189	.....	.....	.....	.....	.....	.....	.....
IV	569	102	144	180	202	.....	.....	.....	.....	.....	.....
V	486	104	143	178	198	215	.....	.....	.....	.....	.....
VI	193	101	137	171	193	208	222	.....	.....	.....	.....
VII	43	105	136	164	186	203	216	227	.....	.....	.....
VIII	6	107	133	158	182	196	208	220	231	.....	.....
X	1	81	119	140	158	169	179	192	203	214	222
Average		103	143	179	199	212	220	225	227	214	222
Increment		103	40	36	20	13	8	5	2	—13	8
Total length (inches)		4.9	6.8	8.6	9.5	10.2	10.5	10.7	10.8	10.2	10.6
Increment		4.9	1.9	1.8	0.9	0.7	0.3	0.2	0.1	—0.6	0.4
Number of fish		1,477	1,477	1,451	1,297	728	242	50	7	1	1

for the individual samples. These comparisons did reveal certain differences in the calculated growth of kiyis in the different collections. The variations resembled those indicated earlier in Tables 3 and 4. When the fish of the 2⅜- and 3-inch-mesh nets were eliminated from the 1931 samples to make them more nearly comparable with the 1932 collections the general agreement among the average calculated lengths of the kiyis of the several localities was improved. The statement made earlier (p. 100) that some of the variations in the size of the fish of corresponding age groups at capture might represent true local differences in growth rate may well apply to the calculated lengths. On the other hand, the same distorting factors (discussed on pp. 97-100) that could have affected the length of the kiyis at capture would also influence the calculated lengths.[11] These factors made so uncertain the real significance of observed differences in growth rate that the combination of the data for all localities appeared to provide the best available measure of the growth in length of the Lake Michigan kiyi.

One possible local difference in the rate of growth in length may be mentioned, however. The first-year calculated lengths of the kiyis from northern Lake Michigan (Manistique and the Fox Islands) were rather consistently higher than those of fish of the same age from other localities. The difference was not large (average of roughly 4 or 5 millimeters) but by reason of its rather consistent occurrence well may be significant.

The discrepancies among the calculated lengths of the age groups (all collections combined) were at times large. These disagreements differed from those typical of "Lee's phenomenon" in that the later rather than the earlier years of life were affected most severely. If the data for age-group II are excepted it can be said that discrepancies between successive age groups were, in general, small for first-year lengths,[12] considerably larger for second-year lengths, and most severe for calculated lengths beyond the second year.

It is not believed that errors due to faults in the method of calculating growth were an important source of the discrepancies in Tables 8 and 9. Although Van Oosten (1929) did find that lengths computed by direct proportion from diameter measurements were not perfectly accurate in the related species, *Leucichthys artedi*, the disagreements that occurred were so small that he held the method to be satisfactory for practical purposes. Furthermore, the discrepancies found by Van Oosten affected chiefly the early rather than the late years of life.

Errors of age determination traceable to the presence of accessory

[11] An exception must be made, of course, for the effects of the time of capture in the growing season.

[12] The validity of this statement is not affected by the distortion brought about by the high first-year lengths of kiyis from northern Lake Michigan. When the samples from the Manistique and Fox Islands areas were excluded the first-year lengths of the female kiyis of the reamaining collections were found to be 101 for age-groups III, IV, and V, 96 for age-group VI, and 99 for age-group VII. Similar computations for the males showed an increase in the total range of variation of l_1 (age-groups III-VI) from 96-101 to 95-101.

checks, so prominent that they were taken as annuli, could have contributed to the discrepancies. Although the reading of the kiyi scales was sufficiently difficult that some incorrect readings almost certainly were made, the number of errors must have been reduced greatly by the discarding of the most difficult scales (more than 5 per cent in northern Lake Michigan samples which contained relatively more old fish). An even stronger argument against errors of age determination as an important source of the discrepancies is to be found in the circumstance that disagreements were present among the second-year lengths and severe among the third-year lengths although the detection of the first three annuli presented a simple problem on almost all scales.

Although the factors just discussed conceivably may have been responsible for some small part of the discrepancies in Tables 8 and 9, it is believed these disagreements can be explained more satisfactorily as the result of gill-net selection and differences in the mortality rate of kiyis with different rates of growth.[13]

The extremely high calculated lengths of age-group II can be attributed primarily to the selection by the gill nets of the larger individuals with the more rapid growth. The relatively poor representation of age-group III in comparison with age-group IV suggests that here too selection took place and the smaller fish with the slower growth rate were not adequately represented in the former group. The effect of gill-net selection on the average calculated lengths of the older age groups is more difficult to judge. The small variations among the length-frequency distributions of the age groups (Table 5) give cause to believe, however, that the representation of the smaller individuals may have been inadequate also in some age groups beyond the III group. The severity of the selection obviously would decrease with increase in age. There is no reason to believe that any of the discrepancies among the very oldest age groups were the result of the selection by the nets of the slowly growing individuals of those ages. If members of these age groups that were larger and faster growing than those taken had been present in the lake they could have been captured by the 2¾- and 3-inch-mesh nets. These nets, however, took relatively few kiyis (Table 6).

When. as with chubs, there is an intensive commercial fishery the capture by the gill nets of the larger members of certain age groups not only serves as a source of bias in the samples but also brings about a gradual modification of the stock with respect to the growth rate of the individuals present. If the gill nets take the larger members of an age group and if, as suggested in the preceding paragraph, this selection affects the members of a single year class year after year (that is, occurs in several age groups) it is inevitable that even perfectly random samples of the fish remaining in the lake will show a diminishing growth rate with each older age group.

[13]Numerous explanations of discrepancies in calculated lengths in addition to those mentioned here can be found in the literature. The present discussion, however, will deal only with factors considered most pertinent to the problem presented by the data for the kiyi.

A greater mortality of the fish with the more rapid growth possibly may occur independently of the destruction by the fishery of the larger members of certain age groups. The calculated lengths of the Silver Lake (Wisconsin) cisco, *Leucichthys artedi*, exhibited discrepancies that resembled closely those shown by the kiyi (Hile, 1936). In Silver Lake, however, the cisco had not been subjected to any fishing mortality at all. After a consideration of the possible sources of the discrepancies Hile concluded that the natural mortality rate of Silver Lake ciscoes that grew rapidly was greater than that of the individuals whose growth was slow. As a result of this correlation of growth rate and length of life each successively older age group was composed of fish with slower and slower growth.

An illustration of the manner in which a higher mortality rate for fish with the more rapid growth can produce discrepancies in calculated lengths similar to those observed in the kiyi is provided by Table 10 which brings out the effect of eliminating the 46 fish above the average size on the determination of the growth history of the V-group females in the Manistique collection of June 14, 1932. When these larger fish were excluded from the sample the agreement between the corresponding calculated lengths of age-groups V and VI was well-nigh perfect.

TABLE 10.—*Effect of the elimination of fish with the more rapid growth on the determination of the calculated lengths of the V-group female kiyis of the Manistique collection of June 14, 1932*

[For comparison, the growth history of the VI-group females is given at the bottom of the table]

Age group	Sample	Number of fish	Length at capture	Calculated standard length (millimeters) at end of year of life					
				1	2	3	4	5	6
V	All in age group.....	98	225	107	145	181	201	220	.....
V	Fish longer than 225 millimeters omitted....	52	216	103	138	173	193	211	.....
VI	All in age group.....	54	229	102	138	174	194	210	225

Regardless of possible uncertainty as to the underlying causes, it is obvious that individual rate of growth and individual length of life are correlated (negatively) in the Lake Michigan kiyi. The resulting fundamental differences in the growth histories of the various age groups diminish the value of a general growth curve derived from the combination of the data for fish of all ages. Certain of the observations made by Hile (1936) on this problem with respect to the Silver Lake cisco apply equally well to the Lake Michigan kiyi:

> The Silver Lake growth data raise a question as to the value and significance of any "general" growth curve in this population. The presentation of a general growth curve involves the tacit assumption that this curve can be taken to represent the course of growth of an individual that is typical of the population as a whole. However, the Silver Lake growth curve was derived from the combination of several age groups whose growth histories were fundamentally different. It appears characteristic of the Silver Lake cisco that individual growth history and individual life span are definitely

correlated. Consequently the combining of all age groups to obtain a general growth curve involves the lumping together of a mass of heterogeneous growth material. The typical individual that such a curve is purported to represent is probably non-existent.

In spite of the defects inherent in the data, the determination of the "general" growth in length of the kiyi seems to be desirable. With the kiyi as with the Silver Lake cisco this general curve probably does not represent the growth of a typical individual. It does, however, provide a picture of the composite growth histories of the heterogeneous materials that came from a heterogeneous population.

No age groups were excluded in the computation of the averages at the bottom of Tables 8 and 9 although the calculated lengths of the II groups and probably of some older age groups as well were too high as the result of gill-net selection. It was believed that the retention of the data for the younger age groups would compensate in some measure the increasingly inadequate representation of the more rapidly growing individuals in the older age groups. The growth in length has been presented graphically for the first 8 years of life (only 7 years for the males) in Figure 1.

The growth of the kiyi is extremely slow. At the end of 4 full years the calculated lengths of both males and females were substantially less than 10 inches. In fact, this length was not attained by the males until the sixth year of life. At the end of 7 years the calculated length of the males was 10.5 inches (221 millimeters); at the end of 8 years the calculated length of the females was 10.8 inches (227 millimeters). Because of the slow growth of the single X-group fish the ninth- and tenth-year calculated lengths of the females were lower than those for the seventh and eighth years. Beyond the second year of life the calculated lengths of the females were 0.2 to 0.6 inch (4 to 11 millimeters) greater than those of the males.

Kiyis of both sexes made by far their best growth in length during the first year of life (nearly 5 inches; about 100 millimeters). The growth rate declined sharply in the second year when the increment of about 2 inches (40-42 millimeters) was less than half that of the first year. The gradual decrease in the later years led to extremely low values of the increments. Fish of neither sex had increments of more than an inch (20 millimeters) in any year beyond the third. In the males the fifth-, sixth-, and seventh-year increments were nearly the same and did not exceed a half inch (9-10 millimeters). The length increment of the females dropped to the even lower value of 0.1 inch (2 millimeters) in the eighth year.

General growth in weight.—The calculated weights for kiyis of the central basins of Lake Michigin and of the Fox Islands district (Table 11 and Fig. 2), which were determined by means of the length-weight equations given on p. 124, correspond exactly with the grand average calculated lengths of Tables 8 and 9. It seemed desirable (in order to facilitate comparisons) to base computations of growth in weight of the fish from the two areas on the grand average calculated

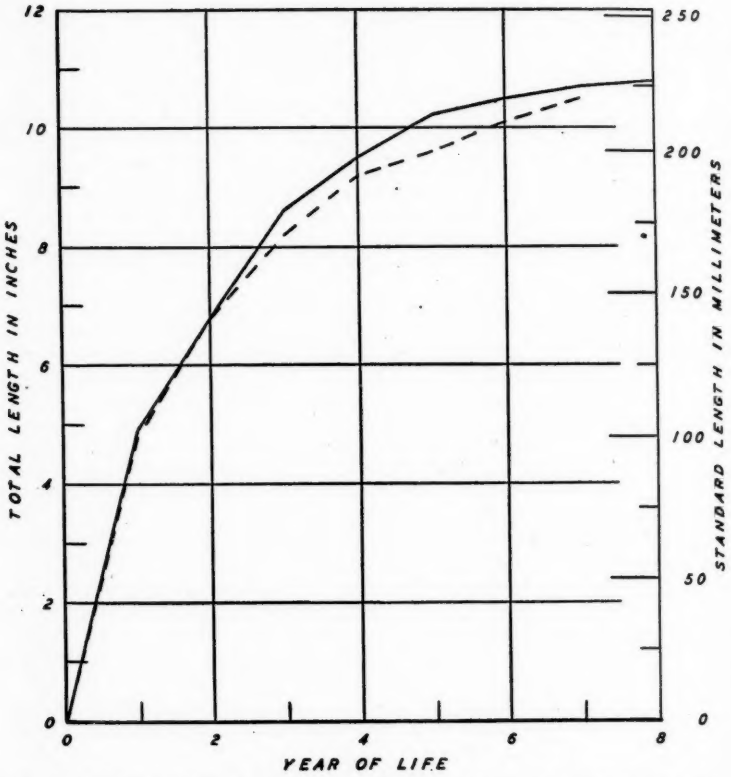

FIGURE 1.—Calculated growth in length of the Lake Michigan kiyi. Solid line, females; broken line, males.

lengths of the combined samples from these areas. This procedure is valid since the growth in length of kiyis apparently was approximately the same in both regions.

In both areas of Lake Michigan the growth in weight was slow. The maximum annual increment of calculated weight, which occurred without exception in the third year of life, was as low as 1.03 ounces or 29 grams (males, Fox Islands) and did not exceed 1.38 ounces or 39 grams (females, central basins of lake). The fourth-year increases of the females were just over 1 ounce but all other increments were less than an ounce. This slow growth is reflected in the amount of time required to attain certain weights. The females did not attain a

TABLE 11.—*Calculated growth in weight of Lake Michigan kiyis*

[The weights, which correspond exactly to the grand average calculated lengths of Tables 8 and 9, were computed by means of the equations given on p. 124]

Year of life	Males				Females			
	Weight (grams)	Increment	Weight (ounces)	Increment	Weight (grams)	Increment	Weight (ounces)	Increment
	Central basins of Lake Michigan							
1	13	13	0.46	0.46	14	14	0.49	0.49
2	39	26	1.38	0.92	40	26	1.41	0.92
3	70	31	2.47	1.09	79	39	2.79	1.38
4	98	28	3.46	0.99	109	30	3.84	1.05
5	113	15	3.99	0.53	133	24	4.69	0.85
6	131	18	4.62	0.63	149	16	5.26	0.57
7	151	20	5.33	0.71	160	11	5.64	0.38
8	.....	.....	.....	.....	164	4	5.78	0.14
9	.....	.....	.....	.....	137	—27	4.83	—0.95
10	.....	.....	.....	.....	153	16	5.40	0.57
	Fox Islands Area							
1	12	12	0.42	0.42	13	13	0.46	0.46
2	35	23	1.23	0.81	36	23	1.27	0.81
3	64	29	2.26	1.03	73	37	2.57	1.30
4	91	27	3.21	0.95	102	29	3.60	1.03
5	105	14	3.70	0.49	124	22	4.37	0.77
6	122	17	4.30	0.60	140	16	4.94	0.57
7	142	20	5.01	0.71	150	10	5.29	0.35
8	.....	.....	.....	.....	154	4	5.43	0.14
9	.....	.....	.....	.....	128	—26	4.51	—0.92
10	.....	.....	.....	.....	144	16	5.08	0.57

calculated weight of a quarter pound before the fifth year of life or the males before the sixth. The females from the central basins of Lake Michigan required more than five growing seasons to reach a weight of 5 ounces while the females from the Fox Islands region and the males from both areas needed more than 6 years to attain that weight.

The annual increments of weight of kiyis of both sexes from both regions of Lake Michigan increased from the first to the third year. Thereafter the increments of the males varied irregularly (decrease in the fifth year; increases in the sixth and seventh years). The weight increments of the female kiyis declined from the fourth through the ninth years of life (were, in fact, negative in the ninth year) but amounted to more than a half ounce in the tenth. Little dependence can be placed, however, on the calculated weights of the females for the ninth and tenth years since they were based on the calculated lengths of a single X-group fish.

The differences between the corresponding calculated weights of kiyis from the central basins of Lake Michigan and from the Fox Islands area can be attributed to the more slender body form of the fish from the northeastern island region. Male kiyis from the former waters were 0.04 ounce (first year) to 0.32 ounce (sixth and seventh years) heavier than males of corresponding age from the latter region. The advantage of the females from the central basins of Lake Michigan ranged from 0.03 ounce (first year) to 0.35 ounce (seventh and eighth years).

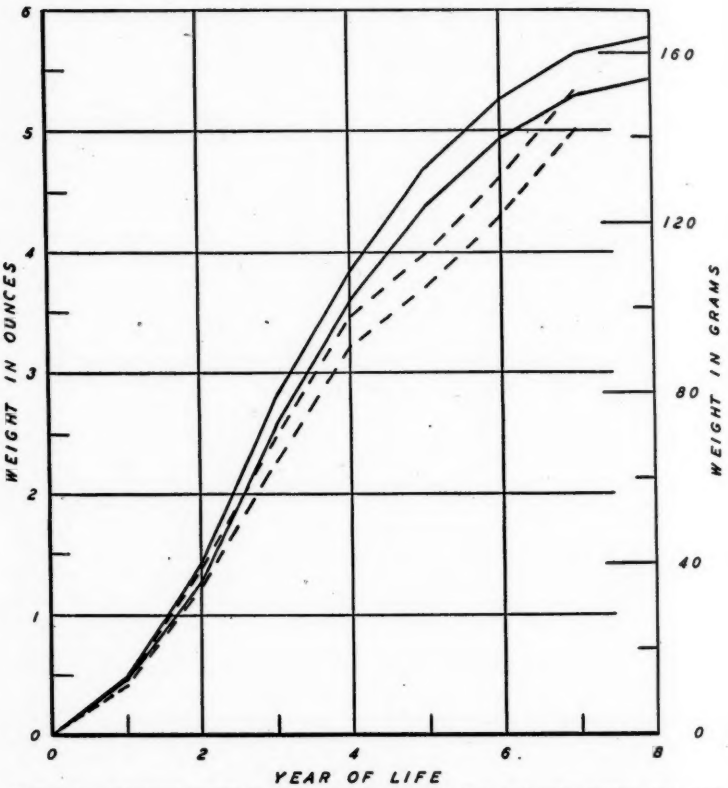

FIGURE 2.—Calculated growth in weight of female (solid line) and male (broken line) kiyis in the central basins of Lake Michigan (upper curves) and in the Fox Islands region (lower curves).

GROWTH COMPENSATION

Growth compensation—the tendency for the smaller young fish to grow more rapidly in the later years of life than do the larger young fish—appears to be characteristic of most coregonids. Growth compensation was observed in the lake herring or cisco (*Leucichthys artedi*) by Van Oosten (1929) and Hile (1936), in the Lake Superior longjaw (*L. zenithicus*) by Van Oosten (1937), in Reighard's chub (*L. reighardi*) of Lake Michigan by Jobes (1943), and in the Lake Huron whitefish (*Coregonus clupeaformis*) by Van Oosten (1939). The phenomenon was not found, however, by McHugh (1941) in any

TABLE 12.—*Relationship between first-year standard length (millimeters) and later growth in length of IV-group female kiyis of the Port Washington, Wisconsin, collection*

Number of fish	Interval of calculated length in millimeters at end of first year	Calculated length at end of year of life					Calculated increment of length in year of life				
		1	2	3	4	[1]5	1	2	3	4	[1]5
49	<90	83	129	166	190	210	83	46	37	24	20
155	90-109	100	141	177	199	215	100	41	36	22	16
63	>109	117	153	186	205	220	117	36	33	19	15
Maximum difference		34	24	20	15	10					

[1]Incomplete season; fish captured on August 13 and 21, 1931.

of the populations of the Rocky Mountain whitefish (*Prosopium williamsoni*) studied by him.

The calculated growth histories of three yearling size groups of IV-group females of the Port Washington, Wisconsin, collection (Table 12) indicate that the kiyi also exhibits growth compensation. Although the largest yearlings had the greatest length and the smallest yearlings the least length at the end of each subsequent year of life and at capture in the fifth summer, the advantage of the large over the small fish decreased each year (progressive decline of the "maximum difference" from 34 millimeters to 10 millimeters). The consistency with which growth compensation took place is brought out by the fact that without exception the size of the calculated annual increments of the three yearling size groups (at right of Table 12) followed the reverse order of the average first-year lengths.

Amount of Season's Growth Completed at Time of Capture

The best information on the increase in length during the growing season was supplied by the three 1932 collections from the Manistique area (Table 13). The calculated increments of length of female kiyis[14] from the time of the formation of the last annulus to the time of capture of the June 14 collection amounted to 39 per cent of the increments of the September 7 sample (the final collection of the year).

Table 13.—*Comparison of the amount of growth (increase of standard length in millimeters) made by female kiyis of five age groups in three collections from the Manistique region from the time of formation of the last annulus up to the time of capture*

[In parentheses, each increment is expressed as a percentage of the increment of the corresponding age group in the September collection]

Date of capture	Age group					Average percentage
	III	IV	V	VI	VII	
June 14, 1932.....	7 (39)	6 (40)	5 (45)	4 (44)	2 (25)	 39
July 9, 1932.....	15 (83)	12 (80)	9 (82)	6 (67)	7 (88)	 80
Sept. 7, 1932.....	18 (100)	15 (100)	11 (100)	9 (100)	8 (100)	 100

On July 9 the kiyis had completed 80 per cent of the growth they would have been expected to make had they survived 2 months longer. Comparisons of the "partial growth" of kiyis captured in June and July indicate that 41 per cent of the total growth to September 7 was made in less than a month. The relatively small increase from July 9 to September 7 (20 per cent of the total growth to the latter date) suggests that growth was extremely slow in the latter part of the season or possibly was terminated earlier than September 7. Indeed, if

[14] Because of the scarcity of males in the collections, this section is based entirely on data for the females. There is no evidence that the course of the season's growth differs in the two sexes.

growth was as rapid or nearly as rapid after July 9 as between June 14 and that date the growing season must have come to an end in the latter part of July. If the growth rate declined gradually after July 9 the end of the season was delayed accordingly.

The lack of collections from the Manistique region later than September 7 makes it impossible to prove the tentative assumption of the preceding paragraph that the 1932 growth actually had been completed by that date (or earlier). Some information on the question can be obtained, nevertheless, from the comparison of the "partial growth" in 1932 up to September 7 with the full-season growth made in the corresponding year of life by members of the next higher age group[15] (Table 14). On first consideration these comparisons would seem to disprove rather than support the belief that the 1932 growth of kiyis from the Manistique area was complete in early September, for the partial growth was without exception less than the full-season growth. It should be remembered, however, that the partial growth was made in 1932 whereas the full-season increments were for 1931. If growth was better in 1931 than in 1932 the discrepancies may be

TABLE 14.—*Comparison of the growth (standard length in millimeters) of certain age groups of female kiyis from the time of formation of the last annulus up to the time of capture with the full-season growth made in the same year of life by fish of the next higher age group*

[Numbers of specimens in parentheses]

Locality	Date of capture	Definition and year of increment	Age group from which partial growth was computed				
			III	IV	V	VI	VII
Manistique	Sept. 7, 1932	Growth in 1932	18 (2)	15 (20)	11 (89)	9 (57)	8 (13)
	.....	Full-season growth,[1] 1931	22 (62)	17 (234)	14 (143)	11 (36)	12 (4)
Fox Islands....	Aug. 13, 1932	Growth in 1932	10 (1)	12 (15)	9 (26)	7 (10)	....
	.....	Full-season growth, 1931	21 (15)	16 (26)	14 (10)	11 (4)	....
Kewaunee	Oct. 15, 1931	Growth in 1931	25 (49)	18 (130)	13 (63)	12 (14)	....
	.....	Full-season growth, 1930	21 (130)	15 (63)	13 (14)	7 (1)	....
Port Washington	Aug. 13 and 21, 1931	Growth in 1931	19 (27)	17 (267)	12 (138)	11 (20)	8 (2)
	.....	Full-season growth, 1930	22 (267)	16 (138)	13 (20)	10 (2)	13 (1)
Racine	Oct. 9, 1931	Growth in 1931	26 (63)	19 (95)	14 (25)	12 (5)	....
	.....	Full-season growth, 1930	23 (95)	18 (25)	13 (5)	9 (1)	....

[1]Determined from the combined collections of June 13, July 9, and Sept. 7, 1932.

[15]Comparisons between groups whose ages differ by more than one year are inadvisable because of the systematic discrepancies between the growth histories of kiyis of different age. Comparisons between consecutive age groups minimize but probably do not eliminate the distorting effects of these discrepancies.

the result of annual fluctuations in growth rate, and therefore not valid evidence for continued growth after September 7.

Although it can not be proved that the growth of the kiyi was better in 1931 than in 1932, comparisons of growth in 1931 and 1930 yield evidence that the 1931 growth may have been somewhat better than average (Table 14). The 1931 growth of kiyis of the Kewaunee and Racine collections captured during the spawning season (at which time the season's growth almost certainly had been completed) exceeded (with the single exception of the Kewaunee V group) the 1930 growth for the corresponding year of life (as computed from fish of the next higher age group). Since these advantages of 1931 over 1930 growth were of approximately the same magnitude as the discrepancies in the Manistique data between the 1931 full-season growth and the 1932 "partial growth" up to September 7, the possibility exists that the discrepancies in the Manistique material also can be attributed to annual differences in growth rate. Consequently, the advantage of the 1931 full-season increments of the Manistique kiyis over the 1932 partial growth for corresponding years of life does not necessarily invalidate the belief (based on the small increase from July 9 to September 7) that growth in 1932 had ended by early September and possibly may have been terminated at an earlier date.

Some additional information on the probable time at which the season's growth of kiyi is completed is provided by the data for the Fox Islands and Port Washington collections, both of which were made up of fish taken near the middle of August. Among the best represented age groups (IV to VI) of the Fox Islands sample the growth increments up to August 13 were 4 or 5 millimeters less than the full-season increments computed from the next higher age groups. To some extent the discrepancies may be the result of differences in growth rate in 1931 and 1932 (see preceding paragraphs). However, the fact that the differences were larger than those shown by the Manistique collection of September 7 gives evidence that growth in the Fox Islands area was not complete on August 13.

Comparisons of the increments for the Manistique and Fox Islands kiyis also suggest the existence of local differences in the course of the season's growth. Although the corresponding full-season increments for the Manistique and Fox Islands fish were nearly the same (Table 14), the Manistique kiyis of age-groups IV and V had grown as much by July 9 (Table 13) as the Fox Islands fish of the same age had grown by August 13 and the "partial growth" of the VI group at Manistique was only 1 millimeter lower than the "partial growth" of the VI group from the Fox Islands.

The 1931 growth of the Port Washington kiyis up to the time of capture in mid-August (August 13 and 21) differed but little from the full-season growth for the same year of life in 1930 ("partial growth" was the larger in age-groups IV and VI and the smaller in age-groups III, V, and VII). This agreement suggests that the 1931 growth had

been nearly if not fully completed by mid-August. It should be remembered, however, that the 1931 growth of kiyis taken later in the season off Kewaunee and Racine exceeded the 1930 growth for the corresponding year of life. If conditions off Port Washington were the same as those off the other two ports, a small amount of growth after mid-August might be expected.

The general conclusion seems warranted that all or most of the kiyi's growth is completed by the end of August. The time at which the growing season ends possibly may be subject to local and annual fluctuations. There is reason to believe, for example, that kiyis from the Fox Islands and Port Washington areas may have continued growth after mid-August while the Manistique data yielded evidence that growth may have ended as early as late July.

That the growth of coregonids can be completed at an early date was demonstrated by Hile (1936) who determined that the Trout Lake (Wisconsin) ciscoes captured at the end of July had completed substantially all of the current season's growth. One of the explanations advanced for the short growing season of the Trout Lake cisco (the seasons were longer for the cisco populations in three other lakes of the same region) was to the effect that the early termination of growth might be associated with an earlier development of the gonads (preliminary to spawning) in the slowly growing Trout Lake stock.

In the event that the cessation of growth and the onset of the prespawning development of the gonads are associated, an early end to the growing season of the kiyi would not be surprising since, according to Hile and Deason (1947), that species spawns rather early in Lake Michigan (peak of spawning activities in late October and early November) for an autmn-spawning coregonid. These authors also presented evidence that the development of the gonads preliminary to spawning may set in at an early date (July or August).

Definite information is lacking on the date at which the growth of the kiyi begins. The fish taken in the Manistique region on June 14 had completed 39 per cent of the growth they would have been expected to make had they survived till September 7. If the growth rate prior to June 14 could be assumed to be approximately the same as that between June 14 and July 9 the beginning of the season could be set a little later than the middle of May. If the early growth rate averaged slower than that between June 14 and July 9, the beginning of the growing season was earlier than the middle of May.

In spite of some uncertainties as to the dates at which the season's growth of the kiyi begins and ends, and in spite of the strong probability of some local and annual variation in these dates, the general conclusion that the growing season is in the neighborhood of 3-3½ months long probably comes near the truth.

If, as estimated above, the seasonal growth of the kiyi begins in May, the time of annulus formation is approximately normal for the latitude (Beckman, 1943). An intriguing question arises, however, con-

cerning the factor or factors that determine the time growth sets in, for the kiyi seems not to experience the sharp rise of water temperature that ordinarily marks the beginning of the growing season. Hile and Deason (1947) have pointed out that in May-November, inclusive, the bulk of the kiyi stock in southern and central Lake Michigan (and almost certainly in northern Lake Michigan also) lives at depths in which the water temperature varies only a fraction of a degree from 4° C. Although we know nothing of the bathymetric distribution of the kiyi between November and May, and information on the annual cycle of temperature changes is incomplete, especially in the great central basins in which most of the kiyis live, the data given by Church (1942) on winter temperatures along the Milwaukee-Muskegon route (this route lies across the shallows separating the two great basins) suggest that the spring rise in temperature of waters inhabited by the kiyi may not be much more than 2° C. (increase from 2° C. in winter to about 4° C. in summer). Church's data suggest also that the kiyi may encounter the highest temperatures of the year in the late fall and early winter. The readings for early and middle December, at which time the lake is vertically almost isothermal, showed temperatures of 5.75° C.-6.00° C. down to depths of about 60 fathoms and greater. In view of this unusual cycle, and the extremely small range of the temperature changes to which the kiyi is exposed, it would appear that if temperature is the factor controlling the seasonal course of growth, the kiyi must be sensitive to extremely small gradients in the spring and fail to react to equally large increases and absolutely higher temperatures in the early winter. More probably the time at which growth begins is determined by some other factor such as food or light.

Length-Weight Relationship

Seasonal, annual, and local differences; general relationship.—Tabulations of the length-weight data of the Lake Michigan kiyi were made originally according to sex, port, and month and calendar year of capture. During the period, May through September, the females were consistently slightly heavier than males of corresponding length. These sex differences usually were small, however (differences between the value of K[16] for males and females ordinarily ran less than 0.05) particularly in comparison with the larger monthly and annual fluctuations. (In the spawning period the extent of sex differences varied according to the state of the organs of the fish in the samples but generally were much larger than in summer; the length-weight relationship of spawning-run fish captured in October and November will be treated in some detail in the next part of this section but for immediate purposes the averages for all fish combined are adequate.) Consequently, the data for the sexes were combined for the study of

[16] $K = \frac{W \times 10^{-6}}{L^3}$, where W = weight in grams and L = standard length in millimeters.

the monthly, annual, and local fluctuations in condition (the sexes followed the same trends in these fluctuations) and for the determination of the general length-weight curves.

The examination of the original tabulations failed to reveal detectable differences in the length-weight relationship of kiyis captured off different ports in the same general region of the lake (southern and northern central basins, northeastern island area). The question of differences between regions can be taken up best after the consideration of monthly and annual fluctuations (Table 15).

TABLE 15.—*Average coefficient of condition, K, according to year and season of capture, in different regions of Lake Michigan, with the data for the sexes combined*

[Number of specimens in parentheses]

Month or months	Southern Lake Michigan		Manistique	Northeastern island region
	1930	1931	1932	1932
May, June, July	.....	1.35	1.39	1.30
	.....	(22)	(693)	(85)
August	1.43	1.50	.....	1.34
	(801)	(584)	.....	(245)
September	.....	1.58	1.45	1.26
	.....	(234)	(467)	(9)
October, November[1]	1.42	1.42	.....	.....
	(22)	(1,534)	.....	.....

[1]See Tables 17 and 18 for values of *K* according to sex and state of organs during the spawning run. Spawning activities in 1931 were underway in late September but the fish of these collections were not weighed.

The best of the none too adequate data on monthly fluctuations in condition,[17] those for southern Lake Michigan in 1931, suggest an increase in the value of *K* from the early season (May, June, and July; only 22 fish employed) through September, followed by a decline at the time of the spawning season (data for fish of all stages of maturity combined). Since figures were available in 1930 for August only it can not be stated whether or not *K* increased during the late summer of that year. The *K* of the October-November fish captured in 1930 (only 22 specimens; data combined without reference to state of organs of the fish) was only slightly smaller than that of fish taken in August. The data for the Manistique area in 1932 suggest an increase in *K* from the early season to September similar (although less pronounced) to that which took place in southern Lake Michigan in 1931. In the northeastern island region, *K* increased slightly in August but fell away in September (only nine fish in the September sample).

The 1930 and 1931 data provide the only available comparisons of

[17]Conclusions as to monthly, annual, and regional fluctuations in the length-weight relationship based on the average coefficient of condition are valid here since the changes of condition with length and the differences in the average lengths in the various collections both were small, and fish of all lengths showed similar variations in condition.

the condition of kiyis from the same region of the lake in different calendar years. The values of K for the spawning-run fish were the same (1.42) in both years. There were relatively few fish, however, in the 1930 collection; furthermore, the values of K of spawning-run samples are affected by the relative abundance of males and females and by the percentage of ripe or ripening and spent fish. Consequently, too great significance should not be assigned to this agreement. The more dependable August data indicate that kivis were relatively heavier in 1931 ($K = 1.50$) than in 1930 ($K = 1.43$).

It would be difficult to state to what extent the differences between the K values for 1931 and for the Manistique collections in 1932 represent annual fluctuation and to what extent they were the result of regional differences. In September the difference was large (1.58 in 1931; 1.45 in 1932). The data for August of 1930 and 1931 provide some evidence, however, that the condition of kiyis may have been somewhat above the average in the latter year. Further argument against the belief that the condition of kiyis of the Manistique area normally differs greatly from that of kiyis of southern Lake Michigan is provided by the fact that in the early season, contrary to the situation in September, the Manistique fish were relatively the heavier. In view of the preceding consideration it has been considered valid to determine a general length-weight curve based on the combination of the data for all collections for the great central basins of the lake.

The length-weight relationship was determined separately for kivis of the island region of northeastern Lake Michigan (about the Manitou, Fox, and Beaver Islands and neighboring reefs, and between these islands and the east shore), since the average values of K for fish from this region were not only consistently lower than those for corresponding months in 1930 and 1931 but were also below the K values for fish captured in the Manistique region in the same year (September comparison, however, based on few specimens from the island area). Possibly the comparatively poor condition of the kivis in the island region can be ascribed to the same unknown factors that caused the fish in the area to be relatively so sparse in comparison with the central basins of the lake (Hile and Deason, 1947).

The general length-weight data of Table 16 are presented graphically in Figure 3. The solid dots show the average weights of kivis from the great central basins of the lake by 5-millimeter intervals of standard length; the open dots give the corresponding information for fish from the island region of northeastern Lake Michigan. The smooth curves are the graphs of the following equations which were fitted to the data for those intervals represented by more than one specimen:

Central basins (upper curve)

$$W = 0.92404 \times 10^{-5} L^{3.077}.$$

Island region (lower curve)

$$W = 0.53314 \times 10^{-5} L^{3.167}.$$

TABLE 16.—*Relationship between the length and the weight of kiyis from the central basins of Lake Michigan, 1930-1932, and from the northeastern island region, 1932*

[The data for the sexes and for the various localities in each region have been combined. The lengths are the midpoints of 5-millimeter intervals of standard length.]

Number of fish	Total length (inches)	Weight (ounces)	Standard length (millimeters)	Weight (grams)	*K*
Central basins					
1	7.0	1.50	147	43	1.35
....	7.5	.....	157	.....	.....
1	7.8	2.00	162	57	1.34
1	8.0	2.50	167	71	1.52
6	8.2	2.25	172	64	1.26
2	8.5	2.25	177	64	1.15
9	8.7	3.02	182	86	1.43
25	9.0	3.39	187	96	1.47
73	9.2	3.59	192	102	1.44
118	9.4	3.88	197	110	1.44
272	9.7	4.30	202	122	1.48
377	9.9	4.61	207	131	1.48
604	10.2	4.95	212	140	1.47
599	10.4	5.25	217	149	1.46
763	10.6	5.53	222	157	1.43
514	10.8	5.84	227	166	1.42
448	11.0	6.18	232	175	1.40
225	11.3	6.50	237	184	1.38
176	11.5	6.91	242	196	1.38
79	11.8	7.32	247	208	1.38
46	12.0	7.66	252	217	1.36
10	12.2	8.05	257	228	1.34
3	12.5	8.87	262	251	1.40
2	12.7	9.50	267	269	1.41
....	12.9	.....	272	.....	.....
2	13.2	10.70	277	303	1.43
1	13.7	11.70	287	332	1.40
Island region					
....	7.0	.....	147	.....	.....
1	7.5	2.00	157	57	1.45
....	7.8	.....	162	.....	.....
....	8.0	.....	167	.....	.....
1	8.2	1.75	172	50	0.98
1	8.5	2.25	177	64	1.15
1	8.7	3.50	182	99	1.64
1	9.0	3.00	187	85	1.30
1	9.2	3.00	192	85	1.20
11	9.4	3.32	197	94	1.23
9	9.7	3.58	202	101	1.23
13	9.9	4.21	207	119	1.34
20	10.2	4.59	212	130	1.36
30	10.4	4.95	217	140	1.37
47	10.6	5.17	222	147	1.34
49	10.8	5.55	227	157	1.34
45	11.0	5.94	232	168	1.35
39	11.3	6.09	237	173	1.30
33	11.5	6.49	242	184	1.30
15	11.8	6.83	247	194	1.29
13	12.0	7.75	252	220	1.37
5	12.2	7.80	257	221	1.30
3	12.5	8.75	262	248	1.38
....	12.7	.....	267	.....	.....
1	12.9	10.25	272	291	1.45
....	13.2	.....	277	.....	.....
....	13.7	.....	287	.....	.....

In both equations W = weight in grams and L = standard length in millimeters.

The examination of the position of the dots in Figure 3 with respect to the curves reveals only a moderately good agreement between the

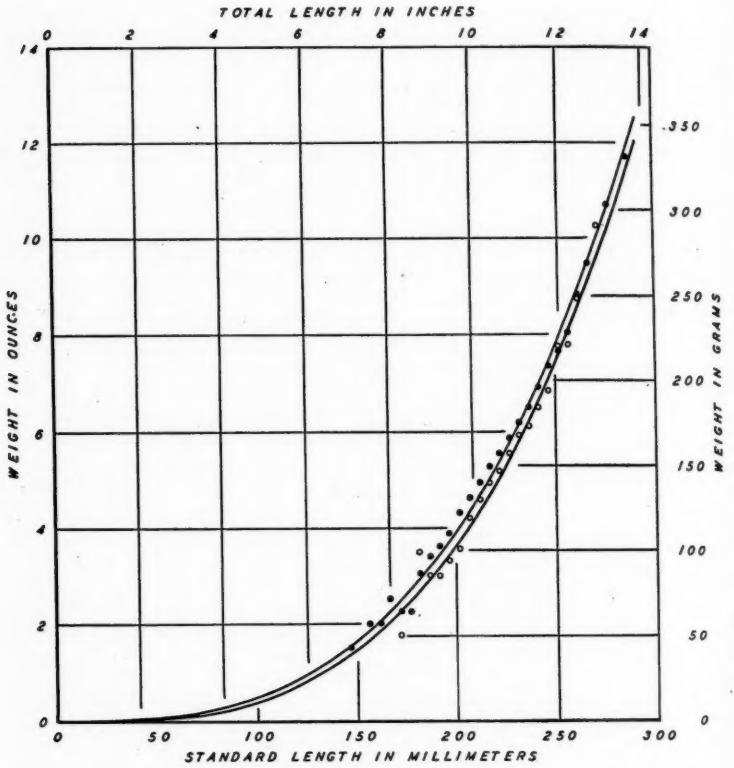

FIGURE 3.—Length-weight relationship of the kiyi in the central basins of Lake Michigan (upper curve and solid dots) and in the northeastern island region (lower curve and open dots). The dots represent the empirical data; the smooth curves are graphs of the equations given in the text.

empirical and theoretical weights. The largest discrepancies, to be sure, are to be found at intervals represented by relatively few fish. On the other hand, disagreements that were consistently in the same direction over fairly large intervals occurred at lengths that were extremely well represented. For example, the actual weights of kiyis from the central basins exceeded the computed weights at every length from 182 millimeters to 227 millimeters, inclusive, although the aver-

ages of 9 of the 10 length intervals were based on 25 fish or more and 7 intervals were represented by more than 100 specimens. In the interval, 237-267 millimeters, the actual weights were consistently lower than the theoretical weights (5 of 7 lengths with 10 fish or more and 2 with more than 100 specimens). The length-weight data for kiyis of the northeastern island region likewise exhibited discrepancies that were consistently in the same direction over considerable intervals of length.

Extremely close agreement between actual and computed weights should not be expected since the empirical values were derived from a combination of all available data regardless of sex, state of organs, or month or year (in the central basins) of capture. Differences traceable to one of these factors together with some variation from sample to sample in the length-frequency distribution of the kiyis doubtless brought about part of the irregularities detectable in the empirical data. Gill-net selection according to condition (see p. 131) also may have played an important role. In view of the logical explanations for the discrepancies between the observed and calculated weights, it may be concluded that the equations may be employed legitimately for the purpose for which they were derived, that of expressing the general length-weight relationship of the kiyi in the two regions of Lake Michigan.

The values of the exponent n in the two equations show that for the collections as a whole the weight of the kiyis increased to a power slightly greater than the cube of the length both in the central basins of Lake Michigan ($n = 3.077$) and in the northeastern island region ($n = 3.167$). When $n > 3$ the coefficient of condition K may be expected to increase with increase in the length of the fish. (This increase in K is to the $n-3$ power of the length.) The actual values of K in Table 16, however, show an extremely irregular variation of the coefficient. These irregularities correspond to the discrepancies between the actual and calculated weights discussed in earlier paragraphs.

In the central basins, 75.9 per cent of all kiyis weighed fell within the size range bounded by the average weights of 4.61 and 6.18 ounces (corresponding total lengths, 9.9 and 11.0 inches). The bulk (71.7 per cent) of the kiyis from the island region were within the interval bounded by the average weights of 4.95 and 6.49 ounces (corresponding total lengths, 10.4 and 11.5 inches). The grand average weights were 5.43 ounces (154 grams) in the central basins and 5.58 ounces (158 grams) in the northeastern islands. The higher average for fish from the island region can be traced to their greater average length—10.8 inches (227 millimeters) as compared with 10.5 inches (220 millimeters) for kiyis from the central basins.

Loss of weight at spawning.—Records of the length and weight of ripe or nearly ripe and spent kiyis of the 1931 spawning run have

made possible a study of the loss of weight at spawning of both males (Table 17) and females (Table 18).[18]

The loss of weight of male kiyis was altogether unimportant. Two of 13 comparisons of fish of the same length interval actually indicated an increase of weight, 2 showed no change, and 9 showed losses that ranged from 0.7 to 7.4 per cent. The mean percentage loss[19] was 1.6.

The loss of weight of female kiyis at spawning was considerable. Every comparison indicated a decrease, with the percentages ranging from 6.2 to 14.4. The variation of these percentages with length exhibited no clear-cut trend although apparently the highest values were at the intermediate lengths. The weighted mean percentage loss was 11.8. Female kiyis, therefore, lost between one eighth and one ninth of their weight at spawning. This estimate should be recognized as minimal, since some individuals designated as ripe may have shed some of their eggs and others listed as spent may still have retained a few.

Comparisons of the grand average values of K in Tables 17 and 18 with those of Table 15 reveal that in 1931 the coefficient of condition was lower among all categories of spawning-run fish, including even the ripe and nearly ripe females, than it was in August and early September before the onset of spawning (these latter averages were based on a combination of the sexes; sex differences were small, however,—see p. 122). The relatively low value of K for the ripe and nearly ripe females is particularly striking since it runs counter to the commonly held belief that fish attain their maximum weight just before spawning. Apparently the weight of kiyis declines from August and early September to the spawning period. At the time the sex products are discharged further loss of weight occurs (large for the females; small for the males).

Effect of gill-net selection on the estimation of the value of the coefficient of condition.—Although numerous investigations have been carried out on the relationship between the size of gill-net meshes and the number and average size of the fish captured, little attention has been given the effect of gill-net selection on the estimation of the value of the coefficient of condition, K. A fairly detailed treatment of this question was made. however, by Farran (1936) who studied the relationship between the K values of marine herring and the size of mesh in drift nets. Farran observed that "the greatest girth of herrings

[18]The data of Tables 17 and 18 were obtained from collections in Wisconsin taken off Kewaunee on October 5 and 15 and November 5, off Sheboygan on November 6, and off Racine on October 9 and 30. The data for certain small, scattered collections and for certain earlier collections that contained few or no spent fish (the category for which information was least plentiful) were not tabulated. The combination of the materials for different localities was made only after the examination of the data proved the procedure to be valid.

[19]In the computation of the mean, each percentage loss was weighted by the product of the number of ripe or nearly ripe and spent individuals involved in the comparison. For example, the first percentage (—8.2) was given a weight, $2 \times 7 = 14$; the second percentage had the weight $6 \times 6 = 36$; . . . .

TABLE 17.—*Comparison of the weights of spent male kiyis of the 1931 spawning run with those of ripe and nearly ripe males of the same length*

[The total lengths are equivalent to the midpoints of the intervals of standard length. See footnote 19 for method of computing the average percentage loss]

Standard length (millimeters)	Total length (inches)	Ripe or nearly ripe			Spent			Loss at spawning	Percentage loss
		Number of fish	Weight (grams)	*K*	Number of fish	Weight (grams)	*K*		
185-189	9.0	2	85	1.30	7	92	1.41	—7	—8.2
190-194	9.2	6	103	1.46	6	101	1.43	2	1.9
195-199	9.4	17	109	1.43	11	109	1.43	0	0.0
200-204	9.7	20	115	1.40	21	111	1.35	4	3.5
205-209	9.9	42	123	1.39	23	123	1.39	0	0.0
210-214	10.2	45	135	1.42	26	133	1.40	2	1.5
215-219	10.4	30	137	1.34	17	132	1.29	5	3.6
220-224	10.6	29	147	1.34	12	143	1.31	4	2.7
225-229	10.8	15	153	1.31	10	152	1.30	1	0.7
230-234	11.0	9	167	1.34	6	158	1.27	9	5.4
235-239	11.3	1	176	1.32	2	163	1.22	13	7.4
240-244	11.5	3	175	1.23	1	190	1.34	—15	—8.6
245-249	11.8	2	188	1.25	2	180	1.19	8	4.3
250-254	12.0	3	191	1.19	.....	.....	.....	.....	.....
275-279	13.2	1	278	1.31	.....	.....	.....	.....	.....
285-289	13.7	.....	.....	.....	1	332	1.40	.....	.....
Total or average		225	.....	1.37	145	.....	1.36	.....	1.6

TABLE 18.—*Comparison of the weights of spent female kiyis of the 1931 spawning run with those of ripe and nearly ripe females of the same length*

[The total lengths are equivalent to the midpoints of the intervals of standard length. See footnote 19 for method of computing the average percentage loss]

Standard length (millimeters)	Total length (inches)	Ripe or nearly ripe			Spent			Loss at spawning	Percentage loss
		Number of fish	Weight (grams)	*K*	Number of fish	Weight (grams)	*K*		
170-174	8.2	1	48	0.94	.....	.....	.....	.....	.....
180-184	8.7	2	89	1.48	.....	.....	.....	.....	.....
185-189	9.0	1	96	1.47	.....	.....	.....	.....	.....
190-194	9.2	10	107	1.51	3	96	1.36	11	10.3
195-199	9.4	19	112	1.46	7	105	1.37	7	6.2
200-204	9.7	55	126	1.53	22	116	1.41	10	7.9
205-209	9.9	88	137	1.54	32	122	1.38	15	10.9
210-214	10.2	137	145	1.52	47	126	1.32	19	13.1
215-219	10.4	141	152	1.49	35	134	1.31	18	11.8
220-224	10.6	175	160	1.46	40	141	1.29	19	11.9
225-229	10.8	100	166	1.42	28	148	1.27	18	10.8
230-234	11.0	71	175	1.40	26	152	1.22	23	13.1
235-239	11.3	41	188	1.41	15	169	1.27	19	10.1
240-244	11.5	29	194	1.37	7	166	1.17	28	14.4
245-249	11.8	11	212	1.41	6	192	1.27	20	9.4
250-254	12.0	5	218	1.36	1	204	1.27	14	6.4
255-259	12.2	3	198	1.17	.....	.....	.....	.....	.....
260-264	12.5	1	281	1.56	.....	.....	.....	.....	.....
275-279	13.2	1	329	1.55	.....	.....	.....	.....	.....
Total or average		891	.....	1.47	269	.....	1.31	.....	11.8

and the girth behind the gill cover . . . are proportional to the condition factor, K, ...", and concluded therefore, " . . . . that the catching power of a net is dependent on the condition of the fish as well as on the length." It follows that the shorter fish captured by a net of a particular mesh size should be the individuals with the greater relative girth (and hence, the higher values of K) whereas the longer fish taken in the same mesh should be those with the smaller relative girth (and the lower values of K). Furthermore, fish of the same length captured in nets of successively larger meshes should have successively greater average values of K.

The effect of gill-net selection on the K of the kiyi was studied for the IV-group females of the Port Washington, Wisconsin, collection. Not only did this sample have the advantage of homogeneity as to age, sex, and maturity (all mature) but all fish were captured off the same port within a relatively short period of time (the dates of collection were August 13 and 21, 1931). The expected relationships outlined at the end of the preceding paragraph are met by the data of Table 19, for the values of K did tend to decrease with increase in

TABLE 19.—*Variation of the coefficient of condition,* K, *of the IV-group female kiyis of the Port Washington collection according to length and to the size of mesh of the gill nets by which they were captured*

[Numbers of specimens in parentheses]

Standard length (millimeters)	Mesh (extension measure in inches)					Average
	2⅜	2½	2⅝	2¾	3	
190-194	....	1.46 (1)	....	....	....	1.46 (1)
195-199	1.60 (1)	....	1.35 (1)	....	....	1.48 (2)
200-204	1.56 (10)	1.64 (6)	1.90 (2)	1.72 (2)	....	1.63 (20)
205-209	1.53 (22)	1.64 (8)	1.72 (3)	1.32 (1)	1.25 (1)	1.56 (35)
210-214	1.50 (26)	1.57 (15)	1.66 (6)	1.60 (6)	1.49 (1)	1.55 (54)
215-219	1.48 (28)	1.53 (15)	1.57 (15)	1.58 (5)	1.82 (1)	1.53 (64)
220-224	1.42 (20)	1.46 (16)	1.56 (12)	1.55 (4)	1.62 (1)	1.48 (53)
225-229	1.48 (5)	1.49 (7)	1.45 (4)	1.56 (8)	1.40 (1)	1.50 (25)
230-234	1.28 (2)	1.50 (2)	1.49 (2)	1.50 (5)	....	1.46 (11)
235-239	....	....	1.49 (1)	....	....	1.49 (1)
240-245	....	1.74 (1)	....	....	....	1.74 (1)
Average K	1.49	1.54	1.58	1.56	1.52	1.53
Average length	214 (114)	215 (71)	217 (46)	220 (31)	216 (5)	216 (267)

length among fish captured in the same net and to increase with increase in mesh size among fish of the same length taken by nets of different mesh. There were, it is true, certain exceptions to the general trends, but relatively few fish were involved. Not only were the numbers of fish too small at certain lengths and for certain meshes to yield reliable averages for *K*, but it is possible also that some of the fish in the poorly represented groups were not caught by the body in the typical manner. The smallest and largest individuals captured by a gill net of a particular mesh size frequently are "accidental" captures, that is, are fish that have become tangled in the meshes by the mouth parts. These fish would not, of course, be subjected to the same selection with respect to condition as those held by the body.

Computations of the average increase of *K* per 5-millimeter increase in length of fish taken in the same nets and of the increase of *K* per ⅛-inch increase in mesh size among fish of the same length interval provide a measure of the selective action of nets with respect to condition. In the calculation of these averages each change of *K* was weighted by the product of the number of fish in each of the two groups compared. (See footnote 19.)

The mean, computed by this procedure, indicated that with kiyis captured by nets of the same mesh the value of *K* decreased 0.034 for each 5-millimeter increase in length. It cannot be stated, however, that this decrease was entirely the result of gill-net selection, for the combined samples of all nets (extreme right of Table 19) also exhibited a decrease in *K* with increase in length (0.026 per 5 millimeters). This latter decline suggests that a drop in *K* with greater length, independent of gill-net selection, may be characteristic of the fish from which the sample was drawn. On the other hand, if it could be assumed that none of the five mesh sizes employed was able to capture the slender individuals among the shorter IV-group females from Port Washington, the decrease in *K* in the complete sample as well as in the samples for the individual nets might be attributed to gill-net selection. At any rate, it should be noted that the decline of *K* with increase in body length was greater in samples of fish caught by nets of the same mesh size than in the combined samples of all nets.

The strongest evidence for a pronounced selective action of gill nets with respect to the coefficient of condition is to be found in the data on the average *K* of fish of the same length interval captured in nets of different mesh size, since the relation of *K* to length in the entire sample has no bearing on the significance of these comparisons. For fish of the same length, each ⅛-inch increase in the mesh size of the gill nets was accompanied by an average increase of 0.057 in the value of *K*. This change amounts to 3.7 per cent of the grand average *K* value of 1.53 for the entire age group.

Comparisons between nets with all lengths of fish combined revealed a smaller increase (0.039) per ⅛-inch increase in mesh size. This smaller increase no doubt can be explained by the tendency for the

nets with successively larger meshes to take fish with greater average lengths. When length increases with increase in mesh size a smaller increase in the relative girth (and hence in condition) is to be expected than when comparisons are limited to fish of the same length.

The data just discussed suggest the advisability of considerable caution in the use of length-weight data from gill-net samples. Since the value of K for fish taken by a particular net is influenced by the size range of the fish available, and since the average K of samples of fish of a particular size is affected by the sizes of gill-net mesh fished, it is obvious that differences in the average values of K in samples from stocks with different size distributions and/or taken by nets of different mesh size may be the result of gear selection and hence in no way reflect true differences in the nature of the populations from which the samples were drawn.

Maturity

The kiyi matures at a small size. Mature females were found down to a standard length of 143 millimeters or a total length of 6.8 inches and mature males down to a length of 146 millimeters or 7.0 inches (no smaller fish were examined). Koelz (1929) made no statement as to the size at maturity of the Lake Michigan or Lake Huron kiyis; in Lake Superior and Lake Ontario, however, the smallest specimens (132 and 148 millimeters, standard length, respectively) were found to be mature.

Only 11 Lake Michigan kiyis of the more than 6,000 examined were immature. Their immaturity was not related to small size for their standard length (10 fish measured) averaged 226 millimeters (total length, 10.8 inches) and ranged from 199 to 258 millimeters (9.5 to 12.3 inches). Inasmuch as these "immature" kiyis averaged as long or longer than fish in the general samples (Table 6) it probably would be more suitable to term them "non-functional." Their presence suggests that "adult" fish occasionally may fail to spawn.

Sex Ratio

The collections of kiyis from Lake Michigan were characterized at all times by a strong preponderance of females (Table 20). The dominance of the females was less pronounced, however, in the spawning-run collections (75.2 per cent of the total) than in late-spring, summer, and early-autumn samples (90.2 per cent of the total).

Sex ratio in summer collections.—The data give no conclusive evidence for a significant monthly fluctuation of the sex ratio over the period, May to mid-September. In 1930 the relative abundance of the sexes was practically the same in July and August, the two months for which data were available. Males appear to have been more plentiful in May, June, and July in 1931 than in August and early September. In 1932 the monthly changes in the sex ratio were irregular. The greatest relative abundance of males in 1932 occurred in June and August and the lowest in July and September. In this last month

TABLE 20.—*Numbers and percentages (in parentheses) of males and females in the kiyi collections of different months, 1930-1932*

Month	1930		1931		1932		1930-1932	
	Males	Females	Males	Females	Males	Females	Males	Females
May	.....	.....	16	80	.....	.....	16	80
	.....	.....	(16.7)	(83.3)	.....	.....	(16.7)	(83.3)
June	.....	.....	16	102	16	202	32	304
	.....	.....	(13.6)	(86.4)	(7.3)	(92.7)	(9.5)	(90.5)
July	53	389	12	39	38	524	103	952
	(12.0)	(88.0)	(23.5)	(76.5)	(6.8)	(93.2)	(9.8)	(90.2)
August	144	985	95	949	22	230	261	2,164
	(12.8)	(87.2)	(9.1)	(90.9)	(8.7)	(91.3)	(10.8)	(89.2)
September (first half)	.....	.....	23	205	18	454	41	659
	.....	.....	(10.1)	(89.9)	(3.8)	(96.2)	(5.9)	(94.1)
Total	197	1,374	162	1,375	94	1,410	453	4,159
	(12.5)	(87.5)	(10.5)	(89.5)	(6.2)	(93.8)	(9.8)	(90.2)
Mid-September to mid-November	6	18	592	1,800	.....	.....	598	1,818
	(25.0)	(75.0)	(24.7)	(75.3)	.....	.....	(24.8)	(75.2)

males were extremely scarce—only 3.8 per cent of the total. The monthly fluctuations in the combined 1930-1932 collections (right of table) have little significance as they are affected too greatly by annual fluctuations in the ratio in combination with differences in the representation of the individual months.

The totals for the "summer" (May to mid-September) collections show a decrease in the percentage of males from 12.5 in 1930 to 10.5 in 1931 and 6.2 in 1932. The difference between 1930 and 1931 was not large. The 1932 percentage, however, was extremely low.

The relationship between the size of the gill-net meshes and the sex ratio of the kiyis captured was investigated in an attempt to learn whether gear selection may account for the small percentage of males in the 1932 samples in comparison with the percentages in 1930 and 1931 and also for the relatively small representation of males in the collections as a whole. This possibility was suggested by the fact that 1932, which was the only year in which 2⅜- and 3-inch-mesh nets were not fished, was also the year in which the percentage of males was lowest.

In view of the slower growth and somewhat more slender form of the males as compared with the females, it might logically be expected that the percentage of males in samples of this small chub should decrease with increase in the mesh size of the gill nets with which the fish were captured. The possibility was considered also that most or all of the mesh sizes in the experimental gill nets might be too large to sample the males as satisfactorily as females and hence that the general scarcity of males in the collections might not reflect at all the relative abundance of the sexes in the population. The data of Table 21, however, fail to reveal a clear-cut relationship between mesh size and the relative abundance of the sexes in samples of kiyis.

TABLE 21.—*Relationship between the mesh size (extension measure in inches) of gill nets and the sex ratio of the kiyis taken*

Year and season	Item	Gill-net mesh				
		2⅜	2½	2⅝	2¾	3
1930 (Summer)	Number of males	104	42	32	4	15
	Number of females	828	284	138	83	41
	Percentage males	11.2	12.9	18.8	4.6	26.8
1931 (Summer)	Number of males	88	38	20	9	7
	Number of females	539	441	229	121	45
	Percentage males	14.0	7.9	8.0	6.9	13.5
1932 (Summer)	Number of males	....	54	31	9	....
	Number of females	....	808	427	175	....
	Percentage males	....	6.3	6.8	4.9	....
1931 (Spawning period)[1]	Number of males	417	119	38	10	7
	Number of females	794	521	344	121	18
	Percentage males	34.4	18.6	9.9	7.6	28.0

[1]One male and two females from a special experimental net were omitted.

In both of the 1931 series of samples the 2⅜-inch-mesh net took a much higher percentage of males than did nets of the next three higher mesh sizes and the trend was toward a lesser relative abundance of males as the mesh size increased. (See two paragraphs later for a discussion of the data for the 3-inch-mesh nets.) In 1930, on the other hand, the percentage of males increased with increase in mesh size from 2⅜ to 2⅝ inches; males were extremely scarce, however, in the samples from the 2¾-inch net. The percentage of males did not vary widely in the samples from the three mesh sizes fished in 1932. The lowest percentage was from the largest mesh, but the smallest mesh did not have the highest percentage.

The data for these same four (or three) mesh sizes indicate also that the percentage of males varied considerably from year to year in samples from the same net. The range of variation (summer collection) was: 11.2-14.0 for the 2⅜-inch-mesh nets (only two years); 6.3-12.9 for the 2½-inch mesh; . . . . These annual differences are of the same general order of magnitude as the differences among the various mesh sizes in the same year.

The figures for the 3-inch-mesh net were omitted from the discussion of the preceding paragraph as not comparable to those for the nets of smaller mesh. Considerable numbers of the fish taken by nets of this mesh are known (from direct observation supported by the examination of the records) to have consisted of small individuals whose mouth parts had become entangled in the webbing. These small fish, which were not caught in the customary manner by gilling, were not subject to the type of selection with which the discussion of the previous paragraphs was concerned. The high percentages suggest that many of them were males. Because of these consistently high percentages the elimination of the 3-inch-mesh net from the experimental series in 1932 very likely had some influence on the determination of the sex ratio in that year. This effect probably was not large as the number of kiyis captured by the 3-inch-mesh nets in earlier years was always small in comparison with the catch of other nets.

The lack of a consistent trend in the fluctuations of the sex ratio of samples of kiyis from nets of successively larger mesh and the rather large variation from year to year in the percentage of males in samples from nets of the same mesh size leave in doubt the effect of gear selection on the value of the ratio. It is possible, indeed probable, that net selection contributed to the low percentage of males in the 1932 collection (in comparison with summer collections of other years) and also to the generally low percentages of males in the samples of kiyis. The available data fail entirely, however, to indicate how extensive this selection might have been.

Differences in the age composition of the samples from different areas of Lake Michigan also may account in part for the fact that the 1932 samples contained relatively fewer males than did the 1930 and 1931 collections. It was brought out earlier (p. 93) that the average age of kiyis was lower in southern Lake Michigan (the region from which the 1930 and 1931 samples were obtained) than in northern Lake Michigan (the scene of the 1932 fishing). Since, as will be shown later in this section, the relative abundance of males tends to decrease with increase in the age of summer-caught kiyis, the scarcity of males in the 1932 samples well may be partly the result of the relatively high average age of the stock in the region in which the collections were made.

The combined possible distorting effects of gear selection and of differences in the age of fish in the samples make it impossible to conclude that the low percentage of males in the 1932 collections reflects a true regional difference in the sex ratio of kiyis taken in summer.

Sex ratio in spawning-run collections.—The available evidence (Table 20) indicates that, as is frequently true among fish, male kiyis are taken more plentifully during the spawning run than at any other period. The relative abundance of males was more than twice as great in the spawning-run samples as in the summer collections of 1931, the only year in which large numbers of fish were collected in both periods. (The numbers of fish taken during the 1930 spawning-run were inadequate, and the close agreement with 1931 with respect to the percentage of males should be considered strictly a coincidence.)

The cause of the greater percentage of males in the spawning-run samples is largely a matter for speculation. A plausible explanation is that based on the assumption that the activity of the males increases greatly during the spawning period. Since the catch of stationary gear is a function both of the number of fish present at a size subject to capture and of their movements, it follows that if the activity of the members of one sex is increased more than that of the other, the percentage representation of the sexes in the catch will be changed even though the relative abundance of males and females on the grounds is not altered.

The high percentage of males in the spawning-run collections of various species frequently has been explained as the result of the ten-

dency for fish of that sex to arrive on the spawning grounds earlier and remain there longer than do the females. This explanation does not appear to be acceptable for the kiyi. The assumption that males are on the spawning grounds in numbers out of proportion to their true abundance in the population carries with it the tacit implication that there exists somewhere a residue of the stock in which males are correspondingly scarce. All the fishing operations during the 1931 spawning season of the kiyi, however, failed to discover this hypothetical portion of the population. Although the sex ratio of samples taken during the spawning period did vary from day to day (Hile and Deason, 1947) the percentages of males were uniformly above the average for the summer samples. It should be emphasized that the operations with experimental gill nets were part of an investigation of all shubs and were not carried out with special reference to the kiyi. The various depths and localities from about 20 fathoms to 90 fathoms were covered with sufficient thoroughness that it is hardly conceivable that portions of the kiyis stock that contained almost no males would not have been found. It is possible, of course, that aggregations of kiyis in which the fish were almost exclusively females may have been present at greater depths than were fished.

It is conceivable also that during the summer a greater proportion of the males than of the females were living somewhat above the bottom beyond the reach of gill nets (which rested on the bottom and were only 5 feet deep) or at greater depths than were fished, whereas during the spawning period the availability of the sexes may have been equal or more nearly equal. In such a situation, barring further complicating effects of a seasonal differential activity of the sexes, the relative numbers of males and females in the catch might reflect their true proportions at the levels and on the grounds fished but not necessarily in the entire population. There is no evidence, however, for such a difference in the distribution of the sexes; in fact, nothing is known of the extent to which fish of either sex may live sufficiently far above the bottom to escape capture by gill nets.

The lack of good evidence as to the validity of any of the preceding explanations forces the general conclusion that the cause of the increase in the abundance of male kiyis in the catch during the spawning season is at yet unknown.

Changes in sex ratio with increase in age.—For the presentation of the data on the variation of the sex ratio with age (Table 22) the order of arrangement of the ports has been varied from that employed in earlier tables. This change has been made to facilitate the comparison of the information for the summer collections (northern Lake Michigan and Port Washington) and the spawning-run samples (Kewaunee and Racine).

The percentage of males decreased rather consistently with the increase in age in the summer collections (exception provided by age-group IV from northern Lake Michigan) through age-group VI or

TABLE 22.—*Representation of the sexes in the age groups of the kiyi collections.*

[Samples were obtained from northern Lake Michigan and off Port Washington during the summer; collections off Kewaunee and Racine were from the spawning run (October)]

Locality	Item	Age group								Total
		II	III	IV	V	VI	VII	VIII	X	
Northern Lake Michigan[1]	Number of males	1	1	8	15	8	1	....	....	34
	Number of females	1	15	77	260	153	40	4	1	551
	Percentage of males	50.0	6.2	9.4	5.5	5.0	2.4	0.0	0.0	5.8
Port Washington, Wisconsin.....	Number of males	1	6	23	9	1	....	....	....	40
	Number of females	....	27	267	138	20	2	1	....	455
	Percentage of males	100.0	18.2	7.9	6.1	4.8	0.0	0.0	....	8.1
Kewaunee, Wisconsin	Number of males	1	19	20	12	1	....	....	....	53
	Number of females	3	49	130	63	14	....	1	....	260
	Percentage of males	25.0	27.9	13.3	16.0	6.7	....	0.0	....	16.9
Racine, Wisconsin	Number of males	4	11	20	8	1	1	....	....	45
	Number of females	22	63	95	25	5	1	....	....	211
	Percentage of males	15.4	14.9	17.4	24.2	16.7	50.0	....	....	17.6
Northern Lake Michigan and Port Washington	Number of males	2	7	31	24	9	1	....	....	74
	Number of females	1	42	344	398	173	42	5	1	1,006
	Percentage of males	66.7	14.3	8.3	5.7	4.9	2.3	0.0	0.0	6.9
Kewaunee and Racine	Number of males	5	30	40	20	2	1	....	....	98
	Number of females	25	112	225	88	19	1	1	....	471
	Percentage of males	16.7	21.1	15.1	18.5	9.5	50.0	0.0	....	17.2

[1]Combined Manistique and Fox Islands collections from State of Michigan waters.

VII beyond which age no males at all were taken. In the combined summer collections the percentage of males declined consistently from the II group to the VII group. The six older fish were all females.

In spawning-run fish from Kewaunee also the relative abundance of the males tended to decrease with increase in age. At Racine, however, the trend was toward an increase in the percentage of males at the higher ages. No trend toward a change of the sex ratio can be discovered in the data for the combined spawning-run samples. The equal relative abundance of males among young and old spawning-run fish is brought out by the fact that members of this sex made up 17.2 per cent of the total number of fish in age-groups II to IV and 17.4 per cent of the individuals older than the IV group.

Of the three conditions, decrease (summer and Kewaunee spawning-run collections), increase (Racine collection), or no change (combined spawning-run collections) in the relative abundance of males with increase in age, the first appears to be the most likely to represent the true trend within the population. Not only did three of four collections (the one from northern Lake Michigan consisted of a combination of four samples) exhibit a tendency toward a decrease in the percentage of males with advancing age, but this type of change is the same that has been observed repeatedly for other species and seems to be common among fish. Furthermore, too great significance should not be given to the exception provided by the Racine collection since the sex ratio is known frequently to be abnormal in spawning-run samples. It may be concluded, therefore, that a decline in the relative abundance of males with increasing age is normal for the Lake Michigan kiyi.

It should be pointed out that the decrease in the percentage of males with increase in age cannot be ascribed logically to gear selection and hence considered an apparent rather than a real phenomenon. The possibility was mentioned earlier in this section that the relatively slowly growing and slender males might have been sampled by the experimental nets less efficiently than females and therefore that gear selection might have contributed to the general scarcity of males in the samples. A selection of this type, however, should tend to cause the relative abundance of the males to increase rather than to decrease with age since the greater size of the older males should permit them to be captured more easily than the younger males.

A progressive decline with increasing age in the relative abundance of males can be explained best on the basis of differential mortality of the sexes. This differential mortality may represent a higher natural death rate of the males or a more rapid rate of destruction in the fishery. Previous investigations have uncovered evidence for both types of differential mortality as a cause of shifting sex ratios. A greater natural death rate for males was considered by Hile (1936) to account for the decrease in the percentage of fish of that sex with increase in age in four cisco populations not subjected to a fishery.

The same author (1941) concluded that a similar change with age in the sex ratio in a stock of rock bass (*Ambloplites rupestris*) also was caused by a relatively high mortality rate for males. On the other hand, Van Oosten demonstrated that selective destruction of the sexes in the commercial fishery provided an adequate explanation of the observed changes in the sex ratio with increasing age in the Lake Huron lake herring[20] (1929) and the Lake Huron whitefish (1939). A similar conclusion was reached by Jobes (MS)[21] for the Lake Erie perch.

It seems likely that in the kiyi fishery the females may suffer the relatively greater destruction at some periods and the males at others. At seasons other than the spawning period the slower growth and more slender form of the males should cause them to become subject to destruction at a later average age than females. During the spawning season, however, the percentage of males in the catch is much greater than at other periods. At that time, therefore, the destruction of males may be relatively greater than that of females. The extent to which these opposing selective actions counteract each other is not known. Consequently no conclusion can be drawn as to the effect of the selective destruction of the sexes of the kiyi in the fishery on the variation of the sex ratio with age.

Conservation of the Kiyi

In view of the increasing importance of the kiyi in the chub fishery of Lake Michigan, it seems advisable to consider briefly the adequacy of current regulations for the protection of the species. In Lake Michigan, chubs have legal protection through regulation of the size of gillnet meshes in all states, from closed seasons in three, and theoretically from a size limit in one. The present (1946) minimum mesh sizes permitted in gill nets employed for taking chubs are 2½ inches, extension measure, in Michigan, Wisconsin, and Indiana and 2⅜ inches in Illinois. The closed seasons for chubs are: Michigan, October 15-November 20; Wisconsin, October 10-November 15; Illinois, October 14-November 10; Indiana, none. Wisconsin has a "general" size limit of 8 inches, total length, which, however is not applied to the chubs.

In all four states bordering on Lake Michigan flexible-rule measurements of gill nets as found in use are specified although not employed in Illinois and Indiana. This method of measurement in effect requires that mesh sizes be approximately ⅛ inch larger than those of corresponding specifications used in the experimental fishing for the kiyis. In other words the 2⅜-inch mesh measured by flexible rule is roughly the equivalent of the 2½-inch mesh of the experimental nets used in this study and the 2½-inch mesh corresponds to the 2⅝-inch mesh. The examination of the data of Table 6 suggests that the present minimum legal mesh sizes, if enforced, can afford considerable pro-

[20] In this fish, contrary to the more usual situation, the males were the more plentiful at the higher ages.

[21] Jobes, Frank W. The age and growth of yellow perch, *Perca flavescens*, (Mitchill), in Lake Erie.

tection to the stocks of the relatively small kiyi. If these mesh sizes are increased further to give more adequate protection to the general chub population the fishing pressure on the kiyi will be even less.

Present closed seasons protect the kiyi during the period of most active spawning—the last half of October and early November (Hile and Deason, 1947). There is no evidence that the species is ever abundant in the shallow waters of Indiana which has no closed season.

The general minimum legal size of 8 inches in Wisconsin, even if enforced, is of no significance to the kiyis as almost none shorter than 8 inches are taken by gill nets within the commercial range of legal mesh sizes (Table 6).

The general conclusion seems warranted that the kiyi receives good protection under current regulations (if enforced) on mesh size and closed seasons and that the improvement of these regulations for the conservation of the chubs as a group will give the species even greater protection. It is not to be inferred, of course, that these safeguards make depletion of the kiyi impossible. An unreasonably intensive fishery can do grievous harm to a stock even under regulations that would ordinarily be considered adequate.

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DISTRIBUTION, ABUNDANCE, AND SPAWNING SEASON AND GROUNDS OF THE KIYI, *LEUCICHTHYS KIYI* KOELZ, IN LAKE MICHIGAN

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CONTENTS

	Page
Abstract	143
Introduction	144
Materials and methods	145
Bathymetric distribution of the kiyi	147
Southern Lake Michigan	147
Northern Lake Michigan	152
Probable factors in the bathymetric distribution of the kiyi	153
Geographical distribution and regional abundance	158
Spawning	159
Literature cited	164

ABSTRACT

From May to November, inclusive, the kiyis of southern Lake Michigan (north to and including localities off Kewaunee, Wisconsin, and Frankfort, Michigan) characteristically inhabit depths of more than 50 fathoms, although small numbers commonly are taken in shallower water (as shallow as 20-29 fathoms). There is evidence that the occasional penetration of relatively large numbers of kiyis into depths of less than 50 fathoms in this area is the result of exceptional hydrographic conditions involving the disturbance of considerable masses of water.

In northern Lake Michigan the scattered lifts made in the region south of Manistique, Michigan, from June to September indicated kiyis to be abundant at depths from 40 to 69 fathoms (no lifts from shallower or deeper water). In northeastern Lake Michigan (Manitou, Fox, and Beaver Islands and the region between these islands and the east shore) kiyis were lacking in all lifts from 20-39 fathoms and were scarce at greater depths (three to four times as abundant, however, at 50-69 fathoms as at 40-49 fathoms).

The consistency with which kiyis remain in water deeper than 40 or 50 fathoms is difficult to explain on the basis of a preference for cold water (about 4°C.). Water of temperatures only a fraction of a degree warmer than that in the region occupied by most kiyis extended up to depths of less than 30 fathoms. Possibly the bathymetric distribution of the kiyi is related to that of its principal food organisms. It was suggested also that the deeper-water habitat may enable the kiyi to avoid strong currents and that an aversion for currents may account for the scarcity of the species in the hydrographically complex northeastern area. Other possible factors are chemical conditions of the water or a preference of kiyis for great pressure and darkness.

The abundance of kiyis appeared to be more or less uniform throughout the great central basins of Lake Michigan, except as related to depths of water. The scarcity of this species in the island region of northeastern Lake Michigan provided the only certain example of a regional difference in abundance.

The survey of 1930-1932 yielded 89 new locality records for the kiyi in Lake Michigan. These localities, together with those reported previously by Koelz (1929), have been charted in Figure 1.

Although the gonads of certain apparently aberrant individuals may ripen as early as mid-July and considerable pre-spawning development of the organs may occur in August, there is no evidence of significant spawning activities of kiyis in southern Lake Michigan before the latter part of September. Spawning continues through at least the first week or two in November and possibly longer. The peak of spawning activity seems to occur in the latter half of October and in early November.

The depth of water on known spawning grounds (all in southern Lake Michigan) was 57.5 to 84 fathoms. There is evidence that the kiyi may spawn in more than 90 fathoms. Spawning appears to be widespread throughout waters of suitable depth.

Introduction

The Great Lakes species of the genus *Leucichthys* other than the shallow-water lake herring (*L. artedi*) are known collectively as chubs and under this designation are the object of a more or less homogeneous fishery. All seven of the described species of Great Lakes chubs occur in Lake Michigan. Chubs are marketed almost exclusively as smoked fish. They are generally considered a great delicacy, and bring a good price.

In the earlier years of the fishery the catch of chubs was composed chiefly of blackfins (*L. nigripinnis*) with a certain number of longjaws (*L. alpenae*) and probably also of *L. johannae*. In more recent years, however, the commercial extinction of the blackfin and the great reduction in the abundance of longjaws (*L. johannae*, now scarce, may never have been plentiful) have forced the fishermen to turn more to the utilization of the smaller species. Today the chub fishery of Lake Michigan is supported to a large extent by the short-jawed chubs (*L. zenithicus* and *L. reighardi*) although the longjaw continues to be common in some localities. In certain regions considerable quantities of the kiyi or paper-belly are taken, and increasing numbers of the larger individuals of the bloater (*L. hoyi*) are marketed. Bloaters are especially common in catches from the Wisconsin waters of Lake Michigan where the stocks of the more valuable chubs have become much reduced.

In spite of the importance of the chubs in the commercial fishery the available scientific information concerning them is relatively limited, and most of the investigations that have been made of the group are recent. Indeed, five of the seven species occurring in Lake Michigan were not described until after 1900 and three of these five species have been described since 1920. To a large degree the studies of the

Great Lakes chubs have been taxonomic and distributional although data on age and growth as well as on other phases of the life histories have been published for *L. kiyi, L. reighardi,* and *L. hoyi,* of Lake Ontario by Pritchard (1931), for *L. zenithicus* of Lake Superior by Van Oosten (1937), and for *L. reighardi* of Lake Michigan by Jobes (1943). A publication by Deason and Hile (1947) on the age and growth of the kiyi in Lake Michigan appears in the same volume with the present paper.

The kiyi was described by Koelz (1921). The same species occurs also in Lakes Superior, Huron, and Ontario. Koelz (1929) considered the Lake Superior and Lake Huron forms to be typical *kiyi,* but assigned the Lake Ontario kiyi to the subspecies *orientalis.* The kiyi can be distinguished from other members of the genus by its large eye, extremely long paired fins, and thinness of body. The lower jaw which extends farther forward than the upper has a pronounced symphisial knob. (See Koelz, 1921 and 1929, for detailed descriptions.) The kiyi is of smaller average size than any other Great Lakes chub except the bloater, *L. hoyi.* It resembles the bloater in that the thin body and relatively dry flesh detract from its market value.

We wish to thank Dr. John Van Oosten, In Charge of Great Lakes Fishery Investigations, Fish and Wildlife Service, for his critical examination of our original manuscript and his excellent suggestions for its improvement. Dr. Frank W. Jobes of the Great Lakes staff kindly prepared the chart showing the geographical distribution of the kiyi in Lake Michigan.

Materials and Methods

The data and materials for the present study were accumulated during the course of experimental fishery operations with chub gill nets carried out by the former U. S. Bureau of Fisheries (now part of the Fish and Wildlife Service) in 1930-1932 with the cooperation of the Conservation Departments of the States of Michigan and Wisconsin and of four manufacturers of net twine. The experimental fishing was conducted from the motor-vessel *Fulmar* in southern Lake Michigan (north to and including waters off Kewaunee, Wisconsin, and Frankfort, Michigan) in 1930 and 1931, and in northern Lake Michigan in 1932.[1] General statements of the purposes and procedure of the experimental chub-net investigations were given by Deason (1932) and Van Oosten (1933).

Standard gangs of gill nets were employed throughout the investigation. In 1930 and 1931 a gang consisted of one net of each of the following sizes of mesh (stretched measure in inches as manufactured): 2⅜, 2½, 2⅝, 2¾, and 3. The 2⅜- and 3-inch-mesh nets were omitted in 1932. Each net was 510 feet long, and 5 feet deep. In 1930 single gangs were set at the various fishing stations. The number of gangs

[1]Since the kiyi does not occur in Green Bay this report is not concerned with the fishing done in that locality.

per lift in 1931 was from one to four (commonly two or three) according to the general abundance of chubs. When the number of nets per gang was reduced to three in 1932 the number of gangs set at each station was increased to as high as seven. All nets were fished on the bottom.

Information on the bathymetric distribution and regional abundance of the kiyi was obtained from the identification of fish taken in 276 lifts of standard five-net gangs in southern Lake Michigan in 1930-1931 and in 315 lifts of standard three-net gangs in northern Lake Michigan in 1932. Records from additional lifts that could not be used in the study of vertical distribution (range of depths covered by the gang too great, chubs not identified from nets of all mesh sizes) nevertheless provided data on geographical distribution.

For the large majority of lifts employed in this study of distribution and abundance every chub was identified as to species. Occasionally, however, when the catches in nets of a particular mesh were large, it was necessary to confine species identification to a sample. The total number of kiyis in the lift from the net or nets of a certain mesh size was then estimated by multiplying the number of kiyis in the sample by the ratio of the total number of all chubs in the catch to the number in the sample. Most of the lifts that were sampled were from nets of the smaller meshes.

Information on which the studies of bathymetric distribution and abundance were based was compiled in terms of the number of fish per lift of a standard gang of gill nets without reference to the length of time the nets had fished. Although the length of the period over which a net is permitted to fish before it is lifted does influence the size of the catch, this effect is far less than would be expected on theoretical grounds, and there is evidence that beyond a certain point the lengthening of the time out fails completely to bring about a significant increase in the quantity of fish taken.[2] Furthermore, the variation in the fishing time of the experimental nets was altogether random (that is, not associated significantly with locality, year, month, or depth of water) within each of the two major regions covered (southern Lake Michigan north to and including grounds near a line connecting Kewaunee, Wisconsin, and Frankfort, Michigan; northern Lake Michigan—waters to the north of the Kewaunee-Frankfort area) and the examination of figures for gangs lifted in the same year and month at a single locality but after different numbers of nights out failed to reveal any detectable effects of fishing time (probably because of the usually small variation in fishing time within an area and because the time out of many of the nets—particularly in southern Lake Michigan—was approaching or had reached the point beyond which no further rise in the catch could be expected to result

[2]See Van Oosten (1935), Hile (1935), and Van Oosten, Hile, and Jobes (1946) for data and comments on the relationship between the number of nights out and the size of the catch of stationary fishing gear in Great Lakes waters.

from increase in the period over which the nets fished).

Although variations in the length of time the nets fished seemingly did not impair the validity of the data for the investigation of bathymetric distribution and for comparisons of abundance within the two major regions mentioned above, the possible effects of this factor on comparisons of abundance in areas in northern Lake Michigan with that in areas in southern Lake Michigan must be recognized. The number of nights out for nets fished in southern Lake Michigan in 1930 and 1931 averaged between 11 and 12 in both years. The gangs fished in northern Lake Michigan in 1932, however, averaged only a little more than 6 nights out. Had the fishing time been as long in northern Lake Michigan as in southern Lake Michigan the catches in the former region without doubt would have been larger; there is, however, no satisfactory basis for an estimate of the extent to which the catch would have been increased.

The investigation of spawning was based principally on the determination of the state of the organs of 2,534 kiyis (561 males; 1,973 females) captured in southern Lake Michigan over the period, August 21-November 6, 1931. The condition of the organs of each fish in these pre-spawning and spawning-run samples was recorded as: M—mature but not nearing ripeness; NR—nearly ripe; R—ripe; or Sp—spent.

Bathymetric Distribution of the Kiyi

Southern Lake Michigan.—Data on the bathymetric distribution of the kiyi in southern Lake Michigan are given in terms of the average number of fish captured per lift of five gill nets (Table 1)—see page 145 for a listing of the mesh sizes. In the compilation of the data for this table the mean of the soundings at the ends of a gang was taken as the depth from which the nets were lifted. Originally, tabulations were made separately for the individual ports according to month and year of capture. Subsequently, combinations were made to the extent that these detailed records seemed to justify.[3]

To a certain degree the combination of the 1930 and 1931 data was arbitrary since lifts were made in both years only in early July, August, and October in the State of Michigan waters of the lake and July, August, and November in Wisconsin[4] waters. The records for southern Lake Michigan for May, June, and September in Michigan and for May, June, September, and October in Wisconsin were based exclusively on 1931 materials.

In the State of Michigan waters of southern Lake Michigan, kiyis were relatively scarce in May at all depths from which lifts were made (Table 1). In the later months they were generally abundant in the

[3]In spite of the general validity of the combinations made of the data for different localities in the same region, a few individual lifts involving the capture of relatively large numbers of kiyis in shallow water (20-49 fathoms) nevertheless required special consideration (p. 151).

[4]For convenience the area fished along the west shore will be termed "Wisconsin" waters, although a few lifts were made in Illinois off Waukegan.

TABLE 1.—*Average number of kiyis taken per gang of five gill nets in southern Lake Michigan (north to and including localities off Kewaunee, Wisconsin, and Frankfort, Michigan) according to depth and month of capture, 1930 and 1931 data combined*

[At left, depths in meters equivalent to the midpoints of the 10-fathom intervals are given in parentheses. In the body of the table the numbers of lifts are shown in parentheses]

Depth (fathoms)	Catch per lift in month (Michigan)							Average	
	May	June	July	August	September	October	November	Weighted	Simple
20-29	.....	2.0	0.3	15.4	2.0	.....	.....	8.1	4.9
(46)	.....	(1)	(6)	(8)	(1)	.....	.....	(16)	
30-39	1.6	1.8	.....	3.0	3.0	15.8	.....	5.6	5.0
(64)	(6)	(5)	.....	(1)	(2)	(5)	.....	(19)	
40-49	0.0	3.0	5.5	.....	4.0	54.3	.....	16.5	13.4
(82)	(1)	(3)	(4)	.....	(1)	(3)	.....	(12)	
50-59	10.0	162.0	40.0	96.8	149.3	62.0	.....	86.5	86.7
(101)	(1)	(2)	(6)	(4)	(3)	(1)	.....	(17)	
60-69	.....	66.7	161.6	81.0	140.3	178.0	.....	114.4	125.5
(119)	.....	(3)	(5)	(7)	(3)	(1)	.....	(19)	
70-79	31.0	.....	.....	.....	55.0	189.0	.....	61.3	91.7
(137)	(4)	.....	.....	.....	(1)	(1)	.....	(6)	
	Catch per lift in month (Wisconsin)[1]								
20-29	0.0	0.0	15.0	1.0	.....	.....	.....	2.0	4.0
(46)	(2)	(4)	(1)	(1)	.....	.....	.....	(8)	
30-39	0.0	1.0	1.0	3.3	1.6	0.8	1.0	1.5	1.2
(64)	(4)	(4)	(7)	(13)	(6)	(9)	(11)	(54)	
40-49	1.5	0.7	1.7	3.6	.....	4.3	4.2	2.5	2.7
(82)	(4)	(11)	(3)	(5)	.....	(6)	(6)	(35)	
50-59	4.0	5.5	25.5	32.0	139.5	110.3	.....	59.3	52.8
(101)	(4)	(4)	(4)	(2)	(4)	(6)	.....	(24)	
60-69	3.5	36.4	42.8	103.5	.....	.....	.....	49.4	46.6
(119)	(2)	(7)	(5)	(4)	.....	.....	.....	(18)	
70-79	.....	.....	129.0	164.3	191.3	217.8	145.1	167.2	169.5
(137)	.....	.....	(2)	(15)	(3)	(4)	(7)	(31)	
80-89	.....	.....	.....	124.5	158.5	238.0	.....	173.4	173.7
(155)	.....	.....	.....	(6)	(2)	(5)	.....	(13)	
90-99	.....	.....	.....	.....	.....	194.7	.....	194.7	194.7
(174)	.....	.....	.....	.....	.....	(3)	.....	(3)	

[1]Includes a few lifts from Illinois waters off Waukegan; one lift (no kiyis captured) at this locality from 10-19 fathoms in November not [illegible] in table.

lifts from water deeper than 50 fathoms but continued to be scarce in most of the shallower lifts. Aside from the sharp break at 50 fathoms there is little evidence for a variation in the abundance of kiyis with depth of water in May, June, August, and September since in each of the larger regions, 20-49 and 50-79 fathoms, the fluctuations in the averages appeared to be random. In July and October, however, the average number of fish per lift increased regularly from the shallower to the deeper waters.

The average catch per gang in shallow water (20-49 fathoms) exceeded the value of 5.5 only three times. The relatively large averages at 20-29 fathoms in August and at 30-39 and 40-49 fathoms in October are believed to be the result of certain unusual conditions which will be discussed later in this section.

At depths of 50 fathoms and greater the average catch per lift after May ranged from 40.0 at 50-59 fathoms in July to 189 (only one lift) at 70-79 fathoms in October. No consistent trend is to be found in the variation of the average catch from month to month in nets set at the same depth or, as mentioned two paragraphs earlier, with depth among nets fished in the same month except July and October.

Because of the advantages attached to each type of average, both the weighted and simple means of the monthly averages have been given at the right of the table. The disagreements between the two sets of values are not large; both bring out clearly the sharp change in the abundance of kiyis at 50 fathoms.

The data on the bathymetric distribution of the kiyi in the Wisconsin waters of southern Lake Michigan agree with those for Michigan waters in that fish were relatively scarce at all depths in May and continued to be scarce during the later months in less than 50 fathoms. Further agreement is to be found in the sharp increase in the average numbers of fish per gang at 50 fathoms. Disagreements between the two sides of the lake are to be observed, however, in the comparatively small averages at 50-59 and 60-69 fathoms in Wisconsin in June and July (in August also at 50-99 fathoms), in the low averages in Wisconsin at 30-39 and 40-49 fathoms in October, and in the variation in the number of kiyis captured at different depths in the same month and at the same depth in different months.

As stated earlier, only in the months of July and October was a trend detectable in the variation of the average number of kiyis per lift with increase in depth in the State of Michigan waters. In Wisconsin, however, a stronger tendency toward an increase in the average with increase in depth is to be noted for both the shallow water (20-49 fathoms) and the deep water (50-59 fathoms). The data for the shallow water exhibit an outstanding exception in the relatively large single life at 20-29 fathoms in July (see p. 151 for a discussion of this high value) but if this discrepancy is disregarded the tendency for the number of fish per lift to increase

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with increase in depth is fairly clear-cut. Exceptions to a similar trend in deeper water occurred at 60-69 fathoms in May, at 80-89 fathoms in August and September, and at 90-99 fathoms in October. These exceptions at 80-89 and 90-99 fathoms suggest that in the deepest water the abundance possibly may decrease with increase in depth.

The Wisconsin data were characterized further by the tendency for the average numbers of kiyi per lift of nets set at the same depth to increase as the season progressed. This trend was lacking in the two shallowest depths (20-29 and 30-39 fathoms) but appeared rather consistently at 40-49 fathoms and deeper. The most serious exceptions are to be found at 50-59 fathoms in October and at 70-79 fathoms in November.

The full-season averages for Wisconsin waters at the right of the table are of limited significance since the lack of data for some depths in certain months together with the tendency for the catch to increase during the season at most levels caused the values of these averages to be a function of the distribution of the available data in time as well as of the fish in the lake. The averages serve nevertheless to bring out the pronounced change in the abundance of kiyis at 50 fathoms.

The general scarcity of kiyis in the May lifts in both Michigan and Wisconsin, their rise in numbers in June in Michigan, and their increasing abundance at most levels during the season in Wisconsin raise the question as to the source of the fish that made the larger catches of the later months possible. Several plausible hypotheses can be advanced in explanation of these seasonal changes in the catch per gang. It is possible, for example, that portions of the stock abandoned a pelagic for a benthic existence and hence became subject to capture in nets set on the bottom, or that in some months kiyis were especially numerous at depths greater than those in which nets were set and that these fish later moved upward to shallower water. Conceivably, too, the growth of young fish may have brought constantly increasing numbers of them to a size at which they could be captured. Finally, it is possible that the increased catches reflected heightened activity rather than greater numbers.

In view of the purely hypothetical nature of the explanations just listed a detailed discussion of the arguments for and against each of them would have little point. Any explanation is handicapped by the necessity for assuming that the factor or factors responsible for the seasonal change in the catch of kiyis per lift operated rather suddenly on the Michigan side of the lake (apparently from May to June) and continually throughout the season (or at least through October) in Wisconsin. This requirement is especially damaging to the theory that the growth of young fish may have made increasing numbers of them available to the nets, since a gradual month-to-month rise in the catch did not occur in Michigan waters.

Mention was made previously (p. 147) of four relatively high monthly averages for kiyis taken in the shallower water (20-49 fathoms)—

see Table 1. Examination of the data for the individual days on which nets were lifted revealed first, that two of the three averages based on more than one lift did not represent the continual capture of kiyis at a high rate, but rather were the result of extremely large catches (for shallow water) made on certain individual days, and second that each of these exceptional lifts from the lesser depths was accompanied by unusual hydrographic conditions in which the disturbance of considerable masses of water could have been involved. The field records revealed also that excessively long fishing time (nights out) could not explain the large catches as the time out for the gangs that took exceptional numbers of kiyis did not vary greatly from the 1930-1931 mean (p. 147) of 11-12 nights out (in fact, four of the seven gangs fished only 8 or 9 days). Information on these large individual inshore lifts and statements of the evidence for unusual hydrographic conditions are given in Table 2.

TABLE 2.—*Particulars concerning lifts (one standard 5-net gang each lift) in which abnormally large numbers of kiyis were taken in shallow water (less than 50 fathoms) together with statements of evidence for accompanying unusual hydrographic conditions*

Port	Date of lift	Depth (fathoms)	Nights out	Number of kiyis taken	Evidence for unusual hydrographic conditions
Two Rivers	July 30, 1930	25-27	9	15	Abnormally low temperatures; readings at 7.7 to 13.1 fathoms were 2.3°C. to 7.5°C. lower than at same depths 9 miles farther offshore on same day and 0.5°C. to 4.7°C. lower than at same station 9 days earlier.
Grand Haven	Aug. 6, 1930	25-26	12	25	Strong currents; nets had shifted southward and one buoy was missing; temperatures, however, about normal on August 6.
Grand Haven	Aug. 14, 1930	25-26	8	73	Strong currents; buoys of offshore gang (in 56 fathoms) completely submerged; heavy swell and current prevented taking of temperature readings.
South Haven	Oct. 28, 1930	33-33.5	12	52	Heavy west and northwest gale, October 16-20, while nets were fishing; heavy weather prevented taking of temperature readings.
Grand Haven	Oct. 22, 1930	45	8	24	See above concerning gale; no temperature readings obtained.
St. Joseph	Oct. 23, 1930	44	8	63	See above concerning gale; temperature of 4.0°C. at 46 fathoms the lowest at this level (40-49 fathoms) during the months, August-November, in 1930 and 1931.
South Haven	Oct. 30, 1930	41	14	76	See above concerning gale; no temperature readings secured (heavy swell).

The large lifts off Two Rivers in July, off Grand Haven in August, and off South Haven from 33-33.5 fathoms in October unquestionably represent deviations from normal conditions. The situation is slightly different with the three lifts from 45, 41, and 44 fathoms, respectively,

off Grand Haven, South Haven, and St. Joseph in October which were the only lifts from 40-49 fathoms in that month in State of Michigan waters. Since, as will be seen in a later section, this month falls within the kiyi's spawning season, the argument might be advanced that the fish had moved inshore to spawn and hence that the presence of considerable numbers of the species at 40-49 fathoms in October is normal for the region. (The same view can not apply to the large catch at 33-33.5 fathoms in October as other lifts from this depth in October were small). This argument appears to be unacceptable, however, as six lifts from 40-49 fathoms in Wisconsin waters in October yielded an average of only 4.3 kiyis per lift.

The data of Table 2, therefore, provide strong evidence for the belief that the occurrence of kiyis in appreciable numbers in the shallow water of Lake Michigan is accompanied by and possibly contingent upon unusual water conditions in the lake (indicated by abnormal temperatures off Two Rivers in July 1930; strong currents off Grand Haven in August 1930; severe gale preceding capture of kiyis off Grand Haven, South Haven, and St. Joseph in October 1930; and low bottom temperature off St. Joseph on October 23). A more detailed consideration of the problem—especially an analysis of wind conditions at and preceding the times of capture of kiyis in shallow water—holds little prospect for profitable results in view of the lack of information on the relationship between winds, their intensity and direction, and the movements of the water (particularly submarine currents) in Lake Michigan.

The question of possible factors controlling the normal bathymetric distribution of the kiyi will be taken up after the presentation of distributional data for northern Lake Michigan.

Northern Lake Michigan.—Local differences in the abundance of kiyis within this region necessitated the consideration of the data on bathymetric distribution in northern Lake Michigan in 1932 separately for the section of the central basin south of Manistique, Michigan, and for the island region of northeastern Lake Michigan. Kiyis were abundant in all lifts from the northern portion of the central basin of the lake. In the northeastern area, however,—out of Charlevoix, Michigan, near the Manitou, Fox, and Beaver Islands, and in the neighborhood of certain reefs (as Richards Reef and Boulder Reef)—they were generally scarce although some fish usually were found in lifts from suitable depths.

Only scattered data were available on the distribution of kiyis off Manistique (Table 3). The largest average[5] for any depth and month was 54.8 at 60-69 fathoms in July, and the smallest was 17.4 at 50-59

[5]Of the five mesh sizes represented in the 1931 nets (p. 145) the 2¾- and 3-inch meshes were omitted in 1932. In southern Lake Michigan in 1930 and 1931 these two nets accounted for 63.0 per cent of the total catch of five nets. (The percentage, computed by state and year, ranged from 60.4 in Michigan in 1930 to 64.2 in Wisconsin in 1931.) Although there is no certainty that similar figures would have been obtained for northern Lake Michigan, the estimate that the averages of Table 3 would have been 2.7 times the values listed had nets of five mesh sizes been fished, may not be far from the truth.

fathoms in the same month. The figures for August and September demonstrate the presence of considerable numbers of kiyis at 40-49 fathoms at the time these samples were taken. (This situation contrasts with that in southern Lake Michigan where kiyis normally were

TABLE 3.—*Average number of kiyis taken per gang of three gill nets in two regions of northern Lake Michigan, according to depth and month of capture, 1932*

[At left, depths in meters equivalent to the midpoints of the 10-fathom intervals are given in parentheses. In the body of the table the numbers of lifts are shown in parentheses]

Depth (fathoms)	Catch per lift in month (Manistique region)				Average	Catch per lift in month (Northeastern region)				Average
	June	July	Aug.	Sept.		June	July	Aug.	Sept.	
20-29	.....	.....	.....	.....	.....	.....	0.0	.....	.....	0.0
(46)	.....	.....	.....	.....	.....	.....	(6)	.....	.....	(6)
30-39	.....	.....	.....	.....	.....	0.0	0.0	0.0	.....	0.0
(64)	.....	.....	.....	.....	.....	(6)	(12)	(28)	.....	(46)
40-49	.....	.....	41.0	33.7	36.1	0.2	0.4	3.1	0.4	1.3
(82)	.....	.....	(7)	(14)	(21)	(22)	(19)	(28)	(8)	(77)
50-59	.....	17.4	.....	.....	17.4	.....	2.8	5.6	4.1	3.9
(101)	.....	(21)	.....	.....	(21)	.....	(59)	(34)	(26)	(119)
60-69	30.4	54.8	.....	.....	46.3	.....	.....	5.8	.....	5.8
(119)	(7)	(13)	.....	.....	(20)	.....	.....	(5)	.....	(5)

scarce in less than 50 fathoms.) The catches were large on each of the three days of collection (seven gangs of three nets lifted each day); the averages per gang were 41.0 on August 27, 37.4 on September 1, and 30.0 on September 7. Whether kiyis were plentiful at 40-49 fathoms at other periods or whether they may have been abundant in still shallower water is not known.

No kiyis were taken in the northeastern island region at depths of less than 40 fathoms. Here, as in southern Lake Michigan, a break occurred at 50 fathoms for the grand average catches at 50-59 and 60-69 fathoms were respectively 3.0 and 4.5 times the average at 40-49 fathoms. The August lifts were greater than those for other months at 40-49 and 50-59 fathoms.

Probable factors in the bathymetric distribution of the kiyi.—Although the kiyi, by reason of its habitation at great depths occupies waters of extremely low temperatures, it is difficult to attribute the general scarcity of the species in depths of less than 50 fathoms (in the Manistique area they seem to be plentiful at 40-49 fathoms as well as in deeper water) to a lack of suitable temperatures. Neither does it seem probable that the occasional presence of considerable numbers of kiyis in the shallower water is to be explained on the assumption that the apparently accompanying disturbances of the lake have brought water of suitable temperature up from the greater depths. An extraordinary sensitivity of kiyis to small gradients would have to be postulated if temperature were to be listed as a principal factor in the bathymetric distribution of the species in any but the shallowest water.

The range of water temperatures in southern Lake Michigan just above the bottom in the depths at which kiyis were most abundant (50-99 fathoms) during the period of this investigation was from 3.75°C.[6] to 4.6°C. However, the highest reading at 40-49 fathoms in any of the months, May through November, was 4.7°C. and no temperature higher than 4.8°C. was observed at 30-39 fathoms before November, or at 20-29 fathoms before August. The differences, therefore, between temperatures of water below 49 fathoms and at 30-49 fathoms up to November (20-29 fathoms also in May through July) were characteristically only a fraction of a degree. Consequently, the failure of the kiyis to occur regularly in appreciable numbers in the shallower water of southern Lake Michigan through October seemingly must be explained on some basis other than water temperatures. Furthermore, the circumstance that kiyis seem generally to avoid depths of less than 50 fathoms in apparently suitable temperatures invites the conclusion that on the occasions of their occurrence in these shallower regions they are simply carried up by the movements of water from the greater depths. In other words, the significant movement may be that of the water mass in which the kiyis live, and no real activity of the fish themselves may be involved.

In the consideration of the relationship between temperature and the bathymetric distribution of the kiyi in northern Lake Michigan, comment may be omitted on the data for the Manistique region (central basin of the lake) as no nets were lifted from less than 40 fathoms (fish were plentiful and temperatures almost uniform—3.85°C. to 4.2°C.—at and below that depth). The bottom-temperature readings in northeastern Lake Michigan are significant, however, in that they fail to explain satisfactorily either the total absence of kiyis in nets fished in that region at depths of 20-39 fathoms (range of temperature, 4.0°C. to 4.9°C.) or their general scarcity at 40 fathoms and deeper (range of temperature, 3.9°C. to 4.8°C.).

The opinion that water temperatures do not provide a satisfactory explanation of the vertical distribution of the kiyi has been expressed with the full realization that many if not most species of fish are capable of perceiving temperature changes of only a fraction of a degree. Indeed, every one of the 19 marine species (13 families) with which Bull (1936) carried out experiments on conditioned responses reacted to temperature increases of less than 0.1°C. The ability of fish to detect such small changes does not mean, however, that they will be confined in nature to waters with a small range of temperature. Several, at least, of the species with which Bull experimented encounter a rather wide range of temperatures during the normal course of their existence.

The failure of water temperature to explain the bathymetric dis-

[6]Consideration of the problem offered by temperature readings of less than 4°C. in summer does not come within the province of this paper. Wright (1931) gave a brief discussion of this question.

tribution of the kiyi (unless, as mentioned earlier, a remarkable sensitivity to small gradients is assumed) makes the cause of their preference for deep water largely a matter of speculation. The distribution of food organisms frequently is the controlling factor in the distribution of fish. Unfortunately nothing is known of the feeding habits of the Lake Michigan kiyi. In Lake Huron, however, Koelz (1929) observed that 20 fish captured off Alpena, Michigan, had eaten *Mysis* almost exclusively. In Lake Ontario, Pritchard (1931) found *Mysis* to be the principal food of 53 kiyis captured off Port Credit, Ontario, whereas *Pontoporeia* ranked first in a sample of two fish from the Main Duck Islands. If the Lake Michigan kiyi has similar feeding habits there may be some significance in Eggleton's (1937) observation that the Lake Michigan bottom fauna (in which *Pontoporeia* is dominant) exhibits a concentration zone at 100-140 meters or 54.7-76.6 fathoms. This distribution of *Pontoporeia* conceivably may account for the scarcity of kiyis in less than 50 fathoms. It leaves unexplained, however, their abundance at 80 fathoms and deeper along the west shore of southern Lake Michigan. Other factors that might affect the bathymetric distribution of the kiyi are the chemical conditions of the water, or a preference by the species for great pressure and darkness. It is possible also that the kiyi avoids currents and that quieter water is available at great depths. Indeed, a preference for quiet water might well explain the scarcity or absence of kiyis in northeastern Lake Michigan where the intricate contours of the island region can be expected to cause considerable turbulence in the northbound current.

Geographical Distribution and Regional Abundance

The data of the present investigation have permitted the addition of 89 locality records for the kiyi in Lake Michigan to the 22 given by Koelz (1929). The two sets of records have been plotted separately in Figure 1.[7] The chart shows also localities at which kiyis were absent from the catch[8] of nets fished in 1930-1932.

The geographic distribution is such as would have been expected from the data on bathymetric distribution in the preceding section where it was stated that kiyis appeared to be widespread and abundant in the deeper water in the great central basins of Lake Michigan, but were not plentiful in the shallow waters of the central basins or in the northeastern island area at any depth. Although kiyis occurred frequently in shallow water (at relatively few stations were none taken), the catches at inshore stations almost always were small.

A more satisfactory comparison of the abundance of kiyis in differ-

[7]Two of the 1930-1932 *Fulmar* stations were so closely adjacent that they could not be charted separately in Figure 1. The number of localities in the figure, therefore, is actually 88.

[8]Fishing localities have not been given for the Green Bay area since no kiyis were taken there by Koelz or during rather extensive operations with the *Fulmar* in 1930 and 1932.

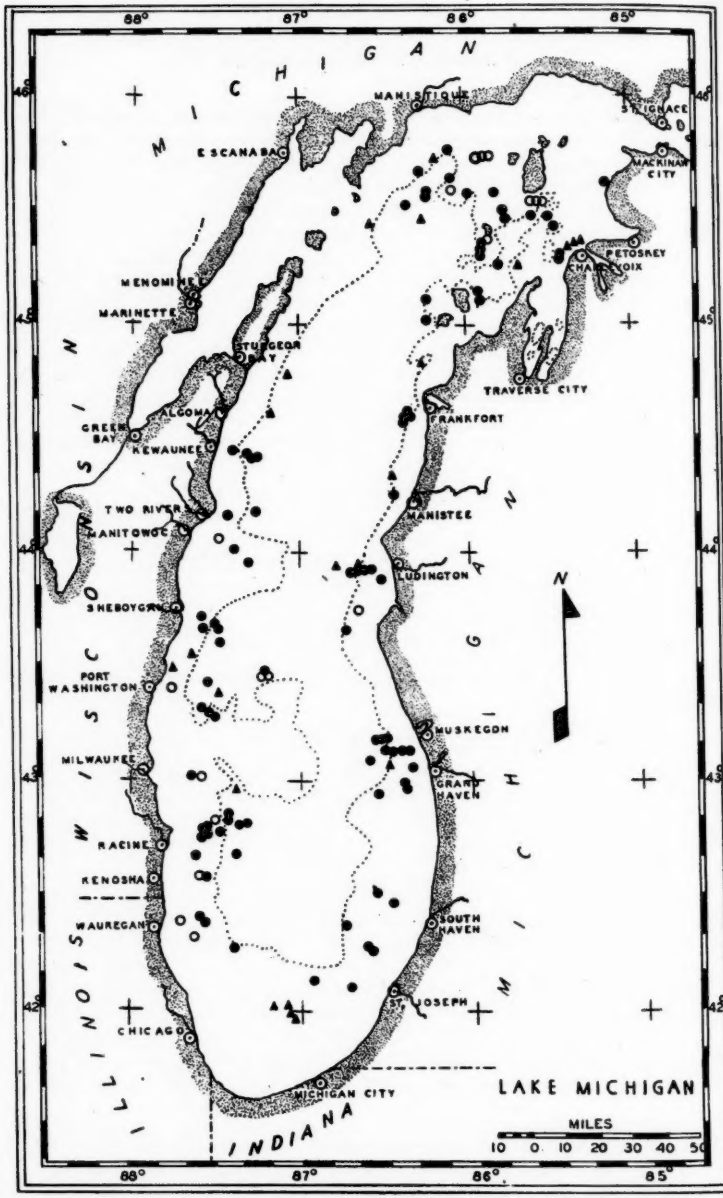

FIGURE 1.—Geographical distribution of the kiyi in Lake Michigan, based on Koelz' (1929) records (triangles) and the 1930-1932 *Fulmar* collections (solid circles). The open circles indicate *Fulmar* stations at which chubs were identified but no kiyis were taken. The dotted line shows the location of the 50-fathom contour.

ent regions of Lake Michigan than is provided by the general statements of the preceding paragraph may be had from figures on the average catch per gang in "shallow water" (less than 50 fathoms in all areas except near Manistique where the division was at 40 fathoms and no lifts were made in less than this depth) and "deep water" (50 or 40 fathoms and more). These averages (Table 4) were all small for shallow water although the value for the State of Michigan waters of southern Lake Michigan was much greater than the values

TABLE 4.—*Average number of kiyis captured per lift of five gill nets at different depths in various regions of Lake Michigan*

[The values for the two northern areas were estimated by multiplying the catch of three gill nets by 2.7 (see footnote 5). Number of lifts shown in parentheses]

Region	Depth[1]	
	Less than 50 fathoms	50 fathoms and more
Southern (Michigan)	9.2 (47)	95.5 (42)
Southern (Wisconsin)[2]	1.9 (98)	116.1 (89)
Northern (Manistique)	....	89.4 (62)
Northeastern (Island region)	2.1 (129)	10.7 (124)

[1]For the Manistique region the division was at 40 rather than 50 fathoms.
[2]A few lifts from Illinois waters included in average for shallow water.

for the Wisconsin waters of the same region and for the northeastern island area. This higher figure was principally the result of unusually large catches in certain individual lifts (discussed on pp. 150-152). In the deeper waters kiyis were abundant throughout the central basin of the lake but were relatively scarce in the northeastern area.

The comparison of the averages for Michigan and Wisconsin waters of southern Lake Michigan (fishing time does not affect this comparison as the average numbers of nights out was almost identical for the two sides of the lake) suggests a greater abundance of kiyis in the deeper water in the latter area. To some extent, however, the comparison was prejudiced by the fact that many more lifts were made in Wisconsin than in Michigan during the spawning period at which time the catches were exceptionally large (Table 1). A comparison that is in some respects fairer (although based on substantially fewer data) is one made between the unweighted means of the average catch per gang at 50 fathoms or more for depths and months fished simultaneously in both states. This comparison yields the following averages: Michigan—97.6; Wisconsin—82.6. From these figures it would seem that the kiyi was not only more abundant in shallow water on the Michigan side of southern Lake Michigan than on the Wisconsin side, but was also slightly more plentiful in Michigan in the greater depths as well. This second comparison, however, is also subject to prejudice since the majority of the pairs of means fell in the early

season at which time the Wisconsin catches, contrary to the situation in Michigan, tended to be smaller than in the late season. In view of the conflicting results of the two comparisons, both of which are known to have been biased, but in opposite directions, the general conclusion seems warranted that for the season as a whole the abundance of the kiyi in the depths of greatest concentration probably differed little in the Wisconsin and Michigan waters of southern Lake Michigan.

The apparently small difference between the abundance of kiyis in the Wisconsin and Michigan waters of southern Lake Michigan is surprising, since all species of chubs combined were about 2.7 times as abundant on the east as on the west shore (Van Oosten, 1933). An even greater difference was found by Jobes (1943) for *L. reighardi* which was seven times as plentiful along the east as along the west shore of the southern region. Both authors ascribed the relative scarcity of chubs in west-shore waters to the more intensive fishery with nets of smaller meshes in that area.

The failure of this same difference in fishing intensity and mesh size to bring about differences in the abundance of kiyis on the two sides of the lake can be explained plausibly as the result of the species' deep-water habitat. The data of Van Oosten and Jobes yielded strong evidence that for chubs as a group and for *L. reighardi* in particular the interchange between the east-shore and west-shore stocks was relatively limited. The kiyi, however, has the deepest habitat of any of the Lake Michigan chubs now present in significant numbers.[9] Since this preference for deep water carries the kiyi toward the center of the lake, free movement between Michigan waters on one side and Wisconsin and Illinois waters on the other is probable. In that event, fishermen from the two shores probably exploit the same populations and over-fishing on either side may be expected to have approximately equal effects on the abundance of kiyis on both.

Comparisons of abundance between areas in northern and southern Lake Michigan are handicapped by differences in the fishing time (nights out) of nets in the two regions (p. 147). Although there is no sound basis for estimating the extent of the increases it is relatively certain that the averages of Table 4 for the northern waters would have been larger had the nets there been permitted to fish as long as did the gangs set in southern Lake Michigan. For the Manistique area the increase probably would have raised the average to somewhere near the values for the southern region. Consequently, the general conclusion is warranted that in 1930-1932 the abundance of kiyis was more or less uniform in the deeper waters of the great central basins of Lake Michigan. The conclusion that kiyis were extremely scarce in the northeastern island region of Lake Michigan would not be affected in the slightest by any increase of the averages that could be expected to result from a lengthening of the fishing time.

[9] *L. nigripinnis* and *L. johannae* which also inhabit the deeper waters are both scarce.

Spawning

With the exception of 24 fish captured in November 1930, data on spawning-run kiyis were obtained only in 1931. In 1930, no examinations of the sex organs of kiyis were made between August 21 and November 8. The last lift of kiyis in 1932 was made on September 12 before spawning had begun (some ripe fish but no spent individuals were taken in 1932). Data on collections from the 1931 spawning run (including information on the "pre-spawning" samples of August 21 and September 11) may be found in Table 5. In addition to these spawning-run collections, eight kiyis for which the condition of the gonads was determined were captured along the west shore (off Waukegan, Racine, and Sheboygan) in shallow water (34-44 fathoms) over the period September 24-October 22. Although every state of organs from "mature" to spent was encountered, these fish should be considered stragglers rather than spawning-run samples.

The pre-spawning development of the gonads of female kiyis was well underway in 1931 on August 21 when 178 (69.8 per cent) of 225 individuals were nearly ripe and 1 (0.4 per cent) was ripe. In the same collection only 1 male (a ripe fish) in 31 exhibited pre-spawning development. The percentage of females that were nearly ripe increased from 69.8 on August 21 to 86.8 on September 11 (no ripe fish on the latter date). The males of the September 11 collection were all designated simply as mature. Apparently the development of the gonads preliminary to spawning begins (or is detectable) earlier in the females than in the males.

The first evidence of active spawning was provided by the spent female captured in shallow water off Racine on September 24—see opening paragraph of this section. (A spent female captured off Ludington on August 18 has been considered aberrant.) Further proof that spawning began in the latter part of September may be found in the data for the collections from Racine on September 28 and from Grand Haven on September 29. Spent kiyis of both sexes occurred in each collection and ripe fish were abundant (30.0 per cent of the males and 53.4 per cent of the females at Racine; 20.9 per cent of the males and 39.8 per cent of the females at Grand Haven). Only 1 fish (a "mature' female from Grand Haven) of the total of 474 in the two collections had not yet begun the ripening of the gonads.[10] The state of organs of the kiyis of the October 5 collection from Kewaunee resembled that of fish taken 6 or 7 days earlier off Racine and Grand Haven. The chief differences lay in the higher percentage of ripe males and the lower percentage of ripe females in the Kewaunee sample. Nor did the data for the Racine collection of October 9 differ greatly from those of samples taken 11 days earlier out of the same port. The percentage of ripe males on October 9 was greater than that in the Racine collection of September 28, but the percentage

[10] It is impossible to state whether or not the scattered "mature" individuals of the September 29 and certain later collections ultimately would have spawned.

TABLE 5.—*State of organs and relative abundance of the sexes of kiyis in 1931 collections made before and during the spawning period*

[M=mature but not yet nearing ripeness; NR=nearly ripe; R=ripe; Sp=spent. All data based on samples of the total catch of kiyis except for Grand Haven and for the October 9 lift off Racine]

Date	Port	Males			Females			Percentage males[1]
		State of organs	Number of fish	Percentage	State of organs	Number of fish	Percentage	
August 21	Port Washington	M	30	96.8	M	76	29.8	10.8
		NR	0	0.0	NR	178	69.8	
		R	1	3.2	R	1	0.4	
September 11	Port Washington	M	23	100.0	M	27	13.2	10.1
		NR	0	0.0	NR	178	86.8	
September 28	Racine	NR	62	68.9	NR	84	40.4	30.2
		R	27	30.0	R	111	53.4	
		Sp	1	1.1	Sp	13	6.2	
September 29	Grand Haven	M	0	0.0	M	1	0.8	24.4
		NR	33	76.8	NR	71	53.4	
		R	9	20.9	R	53	39.8	
		Sp	1	2.3	Sp	8	6.0	
October 5	Kewaunee	M	0	0.0	M	2	0.8	18.2
		NR	19	35.8	NR	139	58.4	
		R	34	64.2	R	83	34.9	
		Sp	0	0.0	Sp	14	5.9	
October 9	Racine	NR	19	39.6	NR	105	47.3	17.8
		R	28	58.3	R	104	46.8	
		Sp	1	2.1	Sp	13	5.9	
October 15	Kewaunee	M	0	0.0	M	1	0.4	15.9
		NR	6	12.0	NR	59	22.3	
		R	44	88.0	R	184	69.4	
		Sp	0	0.0	Sp	21	7.9	
October 30	Racine	NR	0	0.0	NR	5	2.5	19.8
		R	26	53.1	R	110	55.3	
		Sp	23	46.9	Sp	84	42.2	
November 5	Kewaunee	M	1	1.8	M	0	0.0	32.8
		R	23	40.3	R	53	45.3	
		Sp	33	57.9	Sp	64	54.7	
November 6	Sheboygan	R	29	24.8	R	56	42.7	47.2
		Sp	88	75.2	Sp	75	57.3	

[1]Males constituted 23.1 per cent of a sample of 364 kiyis from an estimated total catch of 584 off Kewaunee, Wisconsin, on October 24. The state of organs was not determined on that date.

of ripe females was lower, and spent fish were scarce on both dates.

The spawning activities which apparently proceeded slowly during late September and early October seemed to be nearing a peak in mid-October. A large majority of kiyis of both sexes were ripe (88.0 per cent of the males; 69.4 per cent of the females) in the October 15 collection from Kewaunee. Spent fish continued to be scarce, however.

Spawning activities must have been intensive between October 15 and October 30, for 46.9 per cent of the males were spent on the latter date as compared with no spent males on the former, and the percentage of spent females increased from 7.9 to 42.2 over the same period. At the same time the category, nearly ripe, disappeared in the males and was reduced to unimportance (2.5 per cent) in the females.

The percentages of spent kiyis increased further in the collections of November 5 and 6 (57.9 and 75.2 for the males; 54.7 and 57.3 for the females). The presence of large numbers of ripe fish, however, (40.3 and 24.8 per cent for the males; 45.3 and 42.7 per cent for the females) proves that spawning was still proceeding actively toward the end of the first week in November. That spawning may continue to mid-November or later was demonstrated by the presence of 1 ripe male and 9 ripe females among the 24 kiyis captured in 1930 between November 8 and November 15. (Nothing is known concerning the date at which spawning began in 1930.)

In spite of the fact that spawning can not be demonstrated actually to have been in progress over a period of more than approximately 6 weeks in a single year (September 24 to November 6, 1931) it is probable that the true length of the spawning season is as great as 2 months or more.

Not only does the kiyi seem to spawn over a relatively long period; there is evidence also that numbers of fish may begin the pre-spawning development extremely early in the season and that occasionally individuals actually may spawn at an abnormally early date. The earliest pre-spawning development of the organs was observed in northern Lake Michigan where even in July the gonads of a few (about 2 per cent) of the kiyis captured in the Manistique area were designated as nearly ripe or ripe (dates of collection, July 14-July 20, 1932). No data were available from this area in August; in the collections of September 1 and 7, however, 42 per cent of the fish were nearly ripe. None of the kiyis from the northeastern island region in July 1932 but almost 20 per cent of those observed during the first half of August (no data for the second half of the month) were nearly ripe or ripe. Of the nine fish examined from the same area in September four were nearly ripe.

In southern Lake Michigan in 1930 kiyis showing pre-spawning development of the gonads were observed as early as July 30; only 2 per cent, however, of the fish captured over the period, July 30-August

21 (no data from August 21 to November) were nearly ripe or ripe. One individual, a female, captured off Racine on August 20 was spent. In 1931 a spent female was captured off Ludington on August 18. With that exception, however, the first kiyis that were spent or showed a pre-spawning development of the gonads in 1931 occurred in the August 21 collection from Port Washington. In this and later 1931 collections the percentage of nearly ripe or ripe individuals was high.

The percentages at the right of Table 5 indicate that males were relatively more abundant in the earlier and later samples of the spawning run than in those of intermediate dates. (The records for a sample of 364 kiyis, of which 23.1 per cent were males but for which no data on state of organs were obtained, captured off Kewaunee on October 24, 1931, may be included with the percentages of Table 5.) The percentage of males decreased consistently from 30.2 on September 28 to 15.9 on October 15, and thereafter increased (small irregularity on October 30 when the percentage was slightly under the above-mentioned 23.1 per cent) to 47.2 on November 6. At the present no explanation can be offered for these fluctuations.[11] In all spawning-run samples, however, the percentages of males exceeded those of the pre-spawning collections of August 21 and September 11.

Details concerning the location and depth of water for the known spawning grounds of the kiyi (that is, the localities of capture of the spawning-run samples—September 28, 1931, and later—for which data are recorded in Table 5) are given in Table 6. The table contains information also on other localities at which large catches of kiyis were made during the spawning period. Although the state of organs of these fish was not determined the facts that they were taken during the spawning season and in relatively large numbers (178 fish in one five-net gang at Ludington and 189 fish in one gang at Frankfort; the status of the 62 fish from the inshore gang at Frankfort—see footnote 3 to Table 6—is uncertain) make it probable that they were from the spawning run. The three collections from Racine and other samples of kiyis from Sheboygan whose organs were not examined and a catch off Kewaunee for which records of maturity were not obtained (see footnotes 1 and 2 of Table 6) provide evidence for continuous spawning activities on known grounds. Omitted from the table were records for three relatively large lifts (52 to 76 fish per gang) made in 33 to 44 fathoms off South Haven and St. Joseph in October 1930 and for a smaller lift of 24 fish from 45 fathoms off Grand Haven in the same month. The circumstances attending the capture of these kiyis were so unusual (p. 151) that the presence of the fish can not be accepted as proof that the species normally spawns on the grounds from which the samples were taken.

[11] See Deason and Hile (1947) for a discussion of certain problems concerning the relative abundance of the sexes in samples of kiyis.

TABLE 6.—*Location and depth of water for certain known and probable spawning grounds of the kiyi in southern Lake Michigan in 1931*

Port	Date	Course	Distance (miles)	Depth (fathoms)	Number of kiyis per gang
Known spawning localities					
Kewaunee	Oct. 15	EbyS¼S	11.5	84	214
Do.[1]	Oct. 15	do.	11.0	83	254
Do.	Nov. 5	do.	7.5	73	110
Sheboygan[2]	Nov. 6	SE½S	12.7	71	194
Racine	Sept. 28, Oct. 9, Oct. 30	EbyN½N	22.5	59.5	90-226
Grand Haven	Sept. 29	NW⅞W	16.7	57.5	176
Probable spawning localities					
Frankfort[3]	Oct. 2	SWbyS	5.3	78.5	189
Ludington	Oct. 1	WSW⅞W	11.0	61	178

[1]On October 24 three five-net gangs set along the same course and at approximately the same distance as on October 15 but in deeper water (93 fathoms) took an estimated number of 584 fish or 195 per gang.

[2]Other catches at this locality (average per five-net gang) were: October 6—250 fish; October 30—186 fish; November 18—149 fish.

[3]A much smaller lift (62 fish in one five-net gang) was made off Frankfort on this same date in 55.5 fathoms.

The depth of water on the known and probable spawning grounds of the kiyi in 1931 ranged from 57.5 (or possibly 55.5) to 93 fathoms. Since catches in water shallower than 50 fathoms (with the few exceptions discussed on pp. 148-151) were uniformly small during the spawning season as well as other periods, it may be concluded that the kivi not only lives in deep water during late spring and summer but also remains at these great depths to spawn. Furthermore, the presence of relatively large numbers of kiyis in all lifts from deep water in the fall suggests that, in the southern portion of Lake Michigan at least, spawning may take place in all areas of suitable depth (about 50 fathoms to 90 fathoms or more).

The information presented in this section agrees generally with the observations of Koelz (1929). The data inserted in the following quotation were from other portions of the same paper but are not direct quotations.

> No spawning grounds of the species are known positively, but W. B. Chapin, of Frankfort, Mich., states that during October spawning kiyis are taken in the 70-fathom end of the chub nets that are set on the "northwest shoal," about 12 miles to the northwest of Frankfort. Males taken at Sheboygan, Wis., [60 fathoms] on October 1, 1920, showed incipient pearl organs, but none of the females had eggs even approaching the ripe state. At Frankfort on October 4, 1920, [60 to 70 fathoms] a few females were nearly ripe, and many showed well developed eggs. Two pearled males were taken at Michigan City, Ind., on October 11, 1920, [30 to 40 fathoms—kiyis "rare" in lift] and a spent female was found there on November 8, 1920, [30 to 38 fathoms—kiyis "rare" in this lift also] among several females that had not yet spawned. If the fish referred to by Mr. Chapin are kiyis on their spawning grounds, then the fish observed by me at Frankfort were those that had not yet ripened sexually; or there may be a variation of a few weeks in the beginning of the spawning season, as in the case of the coregonids of the basin, which spawn in shallower water.

Data obtained by Koelz on the kiyis of Lakes Superior, Huron, and Ontario indicate variation in the spawning season of the species in

different waters. In Lake Superior spawning seems to take place "in late November or early December." Although information was scanty for the Lake Huron kiyi, the state of organs of females captured on October 17 and 20, 1917, suggested that "probably the species spawns during October or November." The Ontario kiyi (subspecies *orientalis*—typical *kiyi* is found in Lakes Michigan, Superior, and Huron) was believed to spawn "in August or thereabouts." This belief was based on the fact that among fish captured on July 19 and 21, 1921, males "were pearled, and females showed well-developed ova, although none were by any means ripe," while males and females captured on September 4, 1923, were spent (males still with pearl organs).

Pritchard (1931), however, stated that the Lake Ontario kiyi spawns "in the late fall and early winter. In 1926, the spawning run began in the latter part of October, and some fish were spawning as late as January 8, 1927."

This disagreement between the observations of two competent investigators raises interesting questions concerning possible variation in the spawning season of the kiyi within a single lake. Although Koelz' data are open to the criticism that his collections before and after the supposed spawning season were made in different years (1921 and 1923), the fact remains that developing and spent fish were taken well in advance of the spawning period given by Pritchard.

It is possible, nevertheless, that the discrepancy between the data of Koelz and Pritchard can be explained. The pre-spawning development of the gonads may take place over a fairly long interval of time. Pritchard observed that in Lake Ontario in summer the kiyis "are found on the bottom, apparently in preparation for spawning." In Lake Michigan, as was mentioned previously, ripening and ripe individuals were observed as early as July (both in northern and southern regions) and single spent fish were captured on August 18 and 20, Some of the kiyis that showed an early development of the gonads (particularly the ripe fish of July and early August and the spent fish of the August samples) doubtless were undergoing or had experienced a premature ripening of the gonads. Koelz himself stated that such premature development occurred frequently in *Leucichthys*. The presence of these aberrant individuals well may lead to difficulties in the determination of the spawning date when the available collections are scattered and relatively small as were Koelz' samples of the Lake Ontario kiyi.

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POPULATION DEPLETION IN BROOK, BROWN, AND RAINBOW TROUT STOCKED IN THE BLACKLEDGE RIVER, CONNECTICUT IN 1942

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ABSTRACT

A section of the Blackledge River, 1.7 miles long, was blocked off by weirs and fish traps and a total of 4,757 marked brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Salmo gairdnerii*) were stocked in the experimental area in three plantings. Only a small number of the marked trout attempted to leave the area as indicated by the 46 fish taken in the traps. Subsequent recapture of these trout, which were tagged, indicated no inclination to move any great distance. The mortality of the marked trout after planting was slight during the period of observation, except in one planting where the brook and brown trout stocked showed advanced symptoms of furunculosis. The total catch of marked trout during the season of April 17 to August 31 was 3,446 trout taken by 3,152 anglers spending 9,746 hours on the stream. There was about an 80 per cent return of the available population from each planting and from each of the three species of trout planted. Of the 97 unmarked trout which were caught, only 23 were judged to be "wild" fish, the others being recently stocked trout which had moved into the area from adjoining waters before the weirs were in place. The distribution of the angling pressure was such that each planting was depleted within a few days. About three-fourths of the total catch of trout made from any one planting was taken within four days of the date of stocking. The population of brook trout was depleted most rapidly, that of brown trout most slowly, and rainbow trout were intermediate. Only 5 days of fishing were provided during the season where the catch per unit of effort approached 1 trout per hour or more. There was a high correlation between the population of trout in the stream and the catch per unit effort, except in the second planting of brown trout. The relationship between the available population and the catch per unit effort showed progressively higher yields for the same number of trout as the season advanced. Because of the rapid population depletion, in only one instance could possible differences in behavior between newly stocked trout and those from previous plantings be noted. The number of brown trout caught from the second planting showed no correlation with the fishing effort while brown trout caught from the first planting at the same time were closely related to the fishing effort. The distribution of each angler's catch indicated that under a limit of 15 fish about one-third of the total number of anglers accounted for three-fourths of the catch on the first few days of fishing following each planting.

INTRODUCTION

The practice of planting legal-sized yearling and 2-year-old trout in heavily fished waters of Connecticut furnished fishing where it

otherwise would not exist. The returns from the 1933 tagging experiment (Cobb, 1934) indicated that only about one-third of the stocked fish were recovered by angling during the current season. Later observations on these tagged trout indicated that the hold-over of uncaught trout from season to season was not great. Although the numbers and sizes of trout stocked prior to and during each season provided fishing, the distribution of angling pressure was such that the trout appeared to be depleted within a few days after planting with the result that only fair to poor success would be experienced until the next planting of trout. To study the effect of heavy angling pressure in a Connecticut stream, an experiment was carried out during the 1942 season to investigate the rate of population depletion, the distribution of the angler's catch, the relation between the fish population and catch per unit effort, to gather more data on movement, mortality, and the presence of wild fish in the catch.

Set-up of the Experiment

A State-owned section of the Blackledge River 1.7 miles long, in the towns of Marlborough and Colchester, was selected for the experimental work. This stream is believed to be somewhat typical of many of the trout waters with which the Connecticut stocking program must contend. Water temperatures frequently reach or approach the upper limits of tolerance for trout several times during the summer low-water periods. For example, the afternoon temperatures ranged from 80° to 82° F. on 5 consecutive days during the experimental period in 1942. There is a considerable drop in volume of flow from early spring to summer. The stream bed is composed of rubble, boulders, and some sand, but is not excessively scoured, save in exceptionally high spring floods. The area selected has a number of stream improvement structures, including V-dams, current deflectors, and other devices, and has already been the subject of some experimental work (Hunter, Thorpe, and Grosvenor, 1941).

A fish-tight weir was constructed at either end of the experimental section, each being provided with an upstream and downstream fish trap. Angling was allowed in the area by permit only and a constant patrol was maintained in the test area throughout the open season (April 13 to September 15). Because of forest fire hazards, fishing was prohibited between April 30 and May 6, inclusive. Anglers were checked in and out of the area and data recorded on the number of hours spent fishing, the number of trout caught, method employed (flies or bait), and the distance the angler resided from the stream. Other than this, fishing was permitted under the usual State laws (legal length six inches and creel limit of 15 trout per angler per day).

Three plantings of brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Salmo gairdnerii*) were made. These fish ranged between 8 and 12 inches in total length. The first

of the plantings was on the day before the opening of the season, the other two were during the season (Table 1). The fish in Planting I were marked several weeks prior to planting. Plantings II and III were marked on the day before stocking. Mortality in the hatchery following marking was negligible.

TABLE 1.—*Plantings of marked brook, brown, and rainbow trout made in the experimental section of the Blackledge River, 1942*

Planting	Date	Brook trout	Brown trout	Rainbow trout	Mark	Total	Number trout per mile
I	April 17	798	700	687	right ventral	2,185	1,285
II	April 30	500	500	500	right pectoral	1,500	882
III	June 8	292	292	306	adipose	890	524
Total		1,590	1,492	1,493		4,575	

The stocking procedure was identical with that followed in all of the larger State-controlled waters in that delivery from the hatchery was made by tank truck and distribution in the streams was effected by means of floating live cars and pails.

The weirs were in place on April 16, so that free movement of trout was uninhibited throughout the experimental section prior to this date.

MOVEMENTS OF TROUT

The two-way fish traps on each weir made it possible to capture trout attempting to move up- or downstream out of the area or up- or downstream into the area. The traps were visited twice a day and any trout so captured was tagged with a serial numbered jaw-tag and then released in the direction in which it was attempting to go when it entered the trap. A summary of these moving fish is given in Table 2.

Of the 52 fish moving out of the experimental area, all but 6 were marked. Most of the unmarked fish were judged to be recently planted hatchery fish which had moved into the section from the Salmon River and Fawn Brook prior to the installation of the weirs. The number of marked trout leaving the areas in which they were planted was small, amounting to about one per cent of the total number of trout planted, and these were mainly trout of the first planting (27 of the 46 marked fish). The 27 trout moving into the area were, by their appearance, also largely newly planted stock.

TABLE 2.—*Summary of trout moving into or out of experimental area of Blackledge River, 1942*

Species	Upstream into area	Downstream out of area	Upstream out of area	Downstream into area	Total
Brook trout	11	2	6	1	20
Brown trout	3	8	13	0	24
Rainbow trout	12	19	4	0	35
Total	26	29	23	1	79

Of the 79 trout, 32 were caught or picked up dead during the fishing season (Table 3). The greatest distance traveled by any one of the recaptured fish was 2 miles from the point of release and most of the recaptures were made within much shorter distances. In no case did a trout tagged as it was moving upstream at the lower weir move into the trap at the upper weir or *vice versa*.

The low recovery of rainbow trout presumably could be due to a high unobserved mortality of the tagged fish or more extensive movement.

TABLE 3.—*Summary of recoveries of tagged trout, Blackledge River, 1942*

Item	Brook trout	Brown trout	Rainbow trout	Total
Number tagged	20	24	35	79
Recovered dead	3	2	9	14
Caught	9	8	1	18

MORTALITY IN THE STREAM

The mortality observed among the planted trout was not appreciable except in brook and brown trout during the second planting on April 30. A summary of the total number of trout recovered dead in the stream is given in Table 4.

The trout in Planting II began to die about five days after planting. Many showed swelling and congestion in the region of the clipped fin; practically all of those examined had the external symptoms of furunculosis (or ulcer disease). It seems likely that introduction into the relatively warmer river water under these conditions was responsible for the high mortality.

It was impossible to recover all of the trout which died in the stream, since those lying in deep pools, under rocks or undercut banks, or removed by scavengers would escape detection. Consequently the figures in Table 4 are minimum estimates.

TABLE 4.—*Observed mortality of marked trout planted in experimental section, Blackledge River, 1942*

Planting	Brook trout	Brown trout	Rainbow trout	Total
I	1	3	14	18
II	154	93	15	262
III	14	10	17	41
Total	169	106	46	321

TOTAL CATCH

The catch and effort for the season until June 30, summarized by days, is given in Table 5. For the entire season, 3,152 anglers spent 9,746½ hours to catch 3,446 marked trout (about one trout per angler or 0.4 trout per fishing hour). The returns by angling in terms of the percentage of the total available population (the number planted less the observed dead trout and those moving from the area) is given in Table 6.

TABLE 5.—*Total catch and effort in three plantings of brook, brown, and rainbow trout, Blackledge River, 1942*

Date[1]	Number anglers	Hours fished	Catch—Planting I				Catch—Planting II				Catch—Planting III			
			Brook trout	Brown trout	Rainbow trout	Total	Brook trout	Brown trout	Rainbow trout	Total	Brook trout	Brown trout	Rainbow trout	Total
April 18	219	792	610	141	215	966	.....	.....	.....	.....	.....	.....	.....	.....
April 19	221	688½	42	82	124	248	.....	.....	.....	.....	.....	.....	.....	.....
April 20	91	232½	6	31	24	61	.....	.....	.....	.....	.....	.....	.....	.....
April 21	83	221	9	32	25	66	.....	.....	.....	.....	.....	.....	.....	.....
April 22	108	326½	11	39	51	101	.....	.....	.....	.....	.....	.....	.....	.....
April 23	108	283	1	25	24	50	.....	.....	.....	.....	.....	.....	.....	.....
April 24	52	196	2	30	22	54	.....	.....	.....	.....	.....	.....	.....	.....
April 25	111	327	4	28	20	52	.....	.....	.....	.....	.....	.....	.....	.....
April 26	156	509½	6	31	18	55	.....	.....	.....	.....	.....	.....	.....	.....
April 27	51	142½	0	7	1	8	.....	.....	.....	.....	.....	.....	.....	.....
April 28	37	152½	0	15	8	23	.....	.....	.....	.....	.....	.....	.....	.....
April 29	18	39½	1	4	0	5	.....	.....	.....	.....	.....	.....	.....	.....
May 7	73	211½	2	16	8	26	82	48	123	253	.....	.....	.....	.....
May 8	100	299	7	22	11	40	78	18	84	180	.....	.....	.....	.....
May 9	105	392	1	27	7	35	36	23	47	106	.....	.....	.....	.....
May 10	126	453½	1	14	2	17	6	9	34	49	.....	.....	.....	.....
May 11	52	158½	1	5	3	9	1	6	19	26	.....	.....	.....	.....
May 12	44	123½	1	5	5	11	2	8	4	14	.....	.....	.....	.....
May 13	50	139	0	9	1	10	1	6	17	24	.....	.....	.....	.....
May 14	52	157	2	8	2	12	5	12	20	37	.....	.....	.....	.....
May 15	25	86	0	4	2	6	0	6	4	10	.....	.....	.....	.....
May 16	52	221	0	2	0	2	1	7	12	20	.....	.....	.....	.....
May 17	37	108½	0	2	0	2	0	7	5	12	.....	.....	.....	.....
May 18	7	34½	0	0	0	0	0	1	0	1	.....	.....	.....	.....
May 19	25	83½	0	1	0	1	1	4	5	10	.....	.....	.....	.....
May 20	20	57½	0	0	0	0	1	4	0	5	.....	.....	.....	.....
May 21	33	94½	0	5	1	6	1	9	1	11	.....	.....	.....	.....
May 22	19	61	0	1	0	1	0	3	6	9	.....	.....	.....	.....
May 23	34	126	0	4	0	4	0	18	2	20	.....	.....	.....	.....
May 24	43	124	0	4	0	4	2	10	5	17	.....	.....	.....	.....
May 25	10	37	0	1	0	1	0	2	0	2	.....	.....	.....	.....

May 22	19	126	0	4	0	4	2	10	5	17	.....	.....	.....	.....
May 23	34	124	0	4	0	4	0	2	0	2	.....	.....	.....	.....
May 24	43	37	0	1	0	1	0							
May 25	10													
May 26	20	62	0	0	0	0	0	1	1	2	.....	.....	.....	.....
May 27	29	81	0	0	0	0	0	1	0	1	.....	.....	.....	.....
May 28	31	88½	0	3	0	3	1	3	3	7	.....	.....	.....	.....
May 29	19	51	0	0	0	0	0	1	1	2	.....	.....	.....	.....
May 30	40	97	0	3	1	4	0	3	0	3	.....	.....	.....	.....
May 31	32	103½	0	0	0	0	0	2	1	3	.....	.....	.....	.....
June 1	11	42	0	0	0	0	0	2	0	2	.....	.....	.....	.....
June 2	23	63	0	2	0	2	0	3	0	3	.....	.....	.....	.....
June 3	14	23	0	0	0	0	0	1	1	2	.....	.....	.....	.....
June 4	6	33½	0	0	0	0	0	3	0	3	.....	.....	.....	.....
June 5	24	48	0	0	0	0	0	2	1	3	.....	.....	.....	.....
June 6	44	108	0	2	0	2	0	6	0	6	.....	.....	.....	.....
June 7	26	75	0	0	0	0	0	2	0	2	.....	.....	.....	.....
June 8	39	103½	2	2	1	5	0	0	0	0	107	40	61	208
June 9	95	263½	0	5	0	5	0	6	0	6	115	70	83	268
June 10	49	135½	0	0	0	0	0	1	1	2	7	17	14	38
June 11	32	106½	0	2	0	2	0	3	0	3	6	9	11	26
June 12	23	79	0	1	0	1	0	1	0	1	0	8	5	13
June 13	28	104½	1	4	0	5	0	3	0	3	3	4	8	15
June 14	32	118	0	0	0	0	0	1	0	1	1	10	5	16
June 15	26	79½	0	0	0	0	0	0	0	0	1	4	2	7
June 16	12	38	0	0	0	0	0	1	0	1	0	1	1	2
June 17	28	80	0	0	0	0	0	0	0	0	0	2	3	5
June 18	34	112½	0	0	0	0	0	4	0	4	0	6	1	7
June 19	13	31	0	0	0	0	0	1	0	1	3	0	1	4
June 20	33	90	0	0	0	0	0	1	0	1	0	2	3	5
June 21	25	72½	0	0	0	0	0	0	0	0	0	3	2	5
June 22	13	41½	0	0	0	0	0	0	0	0	0	0	0	0
June 24	21	67	0	3	1	4	0	1	0	1	0	1	3	4
June 25	20	54½	0	0	0	0	0	1	0	1	1	1	0	6
June 26	4	5	0	0	0	0	0	0	0	0	0	0	0	0
June 27	10	53	0	0	0	0	0	1	0	1	1	0	0	1
June 28	20	57	0	0	0	0	0	1	0	1	1	0	3	3
June 29	2	5½	0	0	0	0	0	0	0	0	0	0	0	0
June 30	1	4½	1	0	0	1	0	1	0	1	0	2	1	3
July 1 to Aug. 31	111	291	0	3	0	3	1	5	2	8	1	9	6	16
Season totals	3,152	9,746½	711	625	577	1,913	219	263	399	881	245	197	210	652

[1]No fishing permitted between April 30 and May 6.

TABLE 6.—*Available marked trout population and recovery by angling in experimental section, Blackledge River, 1942*

	Brook trout				Brown trout				Rainbow trout				All species			
Planting	Number available	Catch	Number remaining	Percentage recovery	Number available	Catch	Number remaining	Percentage recovery	Number available	Catch	Number remaining	Percentage recovery	Total available	Total catch	Total remaining	Percentage recovery of total
I	796	711	85	89	683	625	58	92	673	577	96	86	2,152	1,913	239	89
II	344	219	125	64	405	263	142	65	485	399	86	82	1,234	881	353	71
III	279	245	34	88	279	197	82	71	263	210	53	80	821	652	169	79
Total	1,419	1,175	244	83	1,367	1,085	282	79	1,421	1,186	235	83	4,207	3,446	761	82

The total season's returns from the three species of trout (83, 79, and 93 per cent of the number planted for brook, brown, and rainbow trout, respectively) are about the same. The returns from each planting exhibit somewhat more variation, 89, 71, and 79 per cent for Plantings I, II, and III, respectively. It is probable that the high mortality of brook and brown trout in Planting II was responsible for the relatively low yield in this planting. The returns in these two instances may be shown to be significantly below those observed in Plantings I and III. There is obviously no material difference in the returns from the three plantings of rainbow trout.

A total of 97 unmarked trout was also caught: 65 brook trout, 27 brown trout and 5 raibow trout. Many of these fish were obviously hatchery stock which had moved into the controlled section before the weirs were in place. Recognition of "wild" trout (hold-overs from past seasons, or naturally spawned stock) was still a judgment made on arbitrary criteria, principally that of high coloration. Even this judgment became increasingly difficult to make during late season after hatchery stock began to take on more color. Of the total number of unmarked trout which were caught, 14 brook trout and nearly all of the brown trout were of sufficiently high coloration to be classified as "wild" fish. In any event there is no doubt that the fishing supplied by hold-over or naturally produced fish was very small indeed in the experimental section. Both brown trout fry and fingerlings were seined from the stream so some natural reproduction is known to take place.

The fate of the marked trout which were not caught out at the end of the season, of which there was a theoretical population of 761, is unknown. In 11 counts of the trout between the weirs made from September 1 to 20 an average of 30 fish were observed (range of 25 to 37 trout per trip). Granting gross inefficiency of such a method for assessing a population, it was sufficient to indicate that the number of trout remaining in the experimental area was small. Presumably the bulk of the trout which were unaccounted for fell victim to predators or died an unnoticed natural death.

Population Depletion

The rate of population depletion by angling in each of the plantings may be computed by subtraction of each successive day's catch from the total population on hand (Table 5). The population of each species of trout is followed up to 21 days after each planting (Figure 1). It is apparent that each planting was exploited most rapidly in the first few days after stocking. This is largely the direct result of the distribution of angling pressure. There is a decided tendency for anglers to "follow the hatchery truck" with the result that heavy angling pressure invariably follows a new stocking of fish. Brook trout were removed most rapidly, brown trout the most slowly, and rainbow trout were intermediate. The average rate of depletion ex-

pressed as a percentage of the total number of trout taken in each planting is as follows:

Days after stocking	*Percentage caught*
1	37
2	62
3	67
4	74

In other words, with about 75 per cent of the catch removed within 4 days, the remaining 25 per cent supplied the fishing until the next planting. As a study of the catch per unit effort reveals, this was not sufficient to supply satisfactory fishing.

Catch per Unit Effort

The catch per unit of effort has been accepted as a standard to aid in judging fishing success. The catch of marked trout per hour of fishing is given in Table 7. Of the three species stocked, brown trout provide the most sustained fishing, brook trout the highest initial yields and rainbow trout are intermediate. Any apparent discrepancy in this statement in the data on Planting II is no doubt due to the lower population level of brook trout following the heavy mortality. If a standard of one trout per fishing hour is accepted as good fishing (Schuck, 1942), then only about 5 days in the entire 1942 season were good (April 18, May 7 and 8, June 8 and 9).

The decline in catch per hour and the rate of population depletion suggest that these two factors are closely related. Schuck (1942) has demonstrated a significant correlation between populations of brook trout and the catch per hour, but found no correlation in brown trout. In the Blackledge data a reasonably close estimate of the population remaining on any day may be computed by subtracting the catch, migrating individuals and mortality on successive days, starting with the number originally stocked. The catch per hour on any particular day may then be associated with the population remaining on that day.

The relation between population and catch per hour is plotted in Figures 2 to 4 for brook, brown, and rainbow trout in each of the three plantings. The curves have been fitted by linear regression, the equations for each planting are given in Table 8. The possibility of curvilinearity has not been ignored. Inspection of the data seemed to indicate that a straight line gave a reasonable fit. From an inspection of these figures, it is obvious that, with one exception, the population remaining and the catch per unit effort are highly correlated. In the exception, brown trout from Planting II, the scatter of the points is such as to indicate no significant correlation ($r = 0.43$). It is to be concluded that in three different populations of brook trout, three of rainbow trout and two populations of brown trout, the catch per hour was largely determined by the number of trout present. Obviously, more confidence may be placed in the regressions based on populations showing a gradual decline.

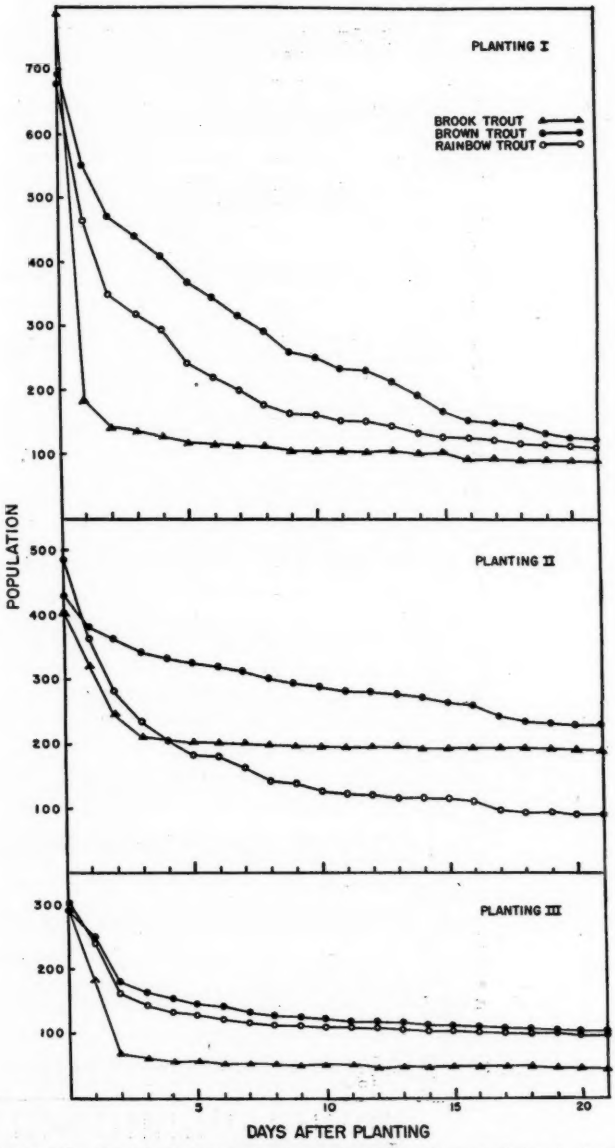

FIGURE 1.—Population depletion in three plantings of marked brook, brown and rainbow trout, Blackledge River, 1942.

TABLE 7.—*Catch per unit effort of three plantings of brook, brown, and rainbow trout, Blackledge River, 1942*

Date[1]	Catch per hour—Planting I				Catch per hour—Planting II				Catch per hour—Planting III				Catch per hour—All plantings			
	Brook trout	Brown trout	Rainbow trout	Total	Brook trout	Brown trout	Rainbow trout	Total	Brook trout	Brown trout	Rainbow trout	Total	Brook trout	Brown trout	Rainbow trout	Total
April 18	0.77	0.18	0.27	1.22	.....	.....	.....	.....	.....	.....	.....	.....	0.77	0.18	0.27	1.22
April 19	0.06	0.12	0.18	0.36	.....	.....	.....	.....	.....	.....	.....	.....	0.06	0.12	0.18	0.36
April 20	0.03	0.13	0.10	0.26	.....	.....	.....	.....	.....	.....	.....	.....	0.03	0.13	0.10	0.26
April 21	0.04	0.14	0.11	0.30	.....	.....	.....	.....	.....	.....	.....	.....	0.04	0.14	0.11	0.30
April 22	0.03	0.12	0.16	0.31	.....	.....	.....	.....	.....	.....	.....	.....	0.03	0.12	0.16	0.31
April 23	0.01	0.09	0.08	0.18	.....	.....	.....	.....	.....	.....	.....	.....	0.01	0.09	0.08	0.18
April 24	0.01	0.15	0.11	0.28	.....	.....	.....	.....	.....	.....	.....	.....	0.01	0.15	0.11	0.28
April 25	0.01	0.08	0.06	0.16	.....	.....	.....	.....	.....	.....	.....	.....	0.01	0.08	0.06	0.16
April 26	0.01	0.06	0.04	0.11	.....	.....	.....	.....	.....	.....	.....	.....	0.01	0.06	0.04	0.11
April 27	0.00	0.05	0.01	0.06	.....	.....	.....	.....	.....	.....	.....	.....	0.00	0.05	0.01	0.06
April 28	0.00	0.10	0.05	0.15	.....	.....	.....	.....	.....	.....	.....	.....	0.00	0.10	0.05	0.15
April 29	0.02	0.10	0.00	0.13	.....	.....	.....	.....	.....	.....	.....	.....	0.02	0.10	0.00	0.13
May 7	0.01	0.08	0.04	0.12	0.39	0.23	0.58	1.20	.....	.....	.....	.....	0.40	0.30	0.62	1.32
May 8	0.02	0.07	0.04	0.13	0.26	0.06	0.28	0.60	.....	.....	.....	.....	0.28	0.13	0.32	0.74
May 9	0.01	0.07	0.02	0.09	0.09	0.06	0.12	0.27	.....	.....	.....	.....	0.09	0.13	0.14	0.36
May 10	0.01	0.03	0.01	0.04	0.01	0.02	0.07	0.11	.....	.....	.....	.....	0.02	0.05	0.08	0.14
May 11	0.01	0.03	0.02	0.06	0.01	0.04	0.12	0.16	.....	.....	.....	.....	0.01	0.07	0.14	0.22
May 12	0.01	0.04	0.04	0.09	0.02	0.06	0.03	0.11	.....	.....	.....	.....	0.02	0.10	0.07	0.20
May 13	0.00	0.06	0.01	0.07	0.01	0.04	0.12	0.17	.....	.....	.....	.....	0.01	0.11	0.13	0.24
May 14	0.01	0.05	0.01	0.08	0.03	0.08	0.13	0.24	.....	.....	.....	.....	0.04	0.13	0.14	0.31
May 15	0.00	0.05	0.02	0.07	0.00	0.07	0.05	0.12	.....	.....	.....	.....	0.00	0.12	0.07	0.18
May 16	0.00	0.01	0.00	0.01	0.01	0.03	0.05	0.09	.....	.....	.....	.....	0.01	0.04	0.05	0.10
May 17	0.00	0.02	0.00	0.02	0.00	0.06	0.05	0.11	.....	.....	.....	.....	0.00	0.08	0.05	0.13
May 18	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03	.....	.....	.....	.....	0.00	0.03	0.00	0.03
May 19	0.00	0.01	0.00	0.01	0.01	0.05	0.06	0.12	.....	.....	.....	.....	0.06	0.06	0.06	0.18
May 20	0.00	0.00	0.00	0.00	0.02	0.07	0.00	0.09	.....	.....	.....	.....	0.02	0.07	0.00	0.09
May 21	0.00	0.05	0.01	0.06	0.01	0.10	0.01	0.12	.....	.....	.....	.....	0.01	0.15	0.02	0.18
May 22	0.00	0.02	0.00	0.02	0.00	0.05	0.10	0.15	.....	.....	.....	.....	0.00	0.06	0.10	0.16
May 23	0.00	0.03	0.00	0.03	0.00	0.14	0.02	0.16	.....	.....	.....	.....	0.00	0.17	0.02	0.19
May 24	0.00	0.03	0.00	0.03	0.02	0.08	0.04	0.14	.....	.....	.....	.....	0.02	0.11	0.04	0.17
May 25	0.00	0.03	0.00	0.03	0.00	0.05	0.00	0.05	.....	.....	.....	.....	0.00	0.08	0.00	0.08

May 25	0.00	0.03	0.00	0.03	0.00	0.05	0.00	0.05	.....	.....	.....	.....	0.00	0.08	0.00	0.08
May 26	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.03	.....	.....	.....	.....	0.00	0.02	0.02	0.03
May 27	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	.....	.....	.....	.....	0.00	0.01	0.00	0.01
May 28	0.00	0.03	0.00	0.03	0.01	0.03	0.03	0.08	.....	.....	.....	.....	0.01	0.07	0.03	0.11
May 29	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.04	.....	.....	.....	.....	0.00	0.02	0.02	0.04
May 30	0.00	0.03	0.01	0.04	0.00	0.03	0.00	0.03	.....	.....	.....	.....	0.00	0.06	0.01	0.07
May 31	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.03	.....	.....	.....	.....	0.00	0.02	0.01	0.03
June 1	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.05	.....	.....	.....	.....	0.00	0.05	0.00	0.05
June 2	0.00	0.03	0.00	0.03	0.00	0.05	0.00	0.05	.....	.....	.....	.....	0.00	0.08	0.00	0.08
June 3	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.09	.....	.....	.....	.....	0.00	0.04	0.04	0.09
June 4	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.09	.....	.....	.....	.....	0.00	0.09	0.00	0.09
June 5	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.06	.....	.....	.....	.....	0.00	0.04	0.02	0.06
June 6	0.00	0.02	0.00	0.02	0.00	0.06	0.00	0.06	.....	.....	.....	.....	0.00	0.07	0.00	0.07
June 7	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03	.....	.....	.....	.....	0.00	0.03	0.00	0.03
June 8	0.02	0.02	0.01	0.05	0.00	0.00	0.00	0.00	1.03	0.39	0.59	2.01	1.05	0.40	0.60	2.06
June 9	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.44	0.26	0.31	1.02	0.44	0.30	0.31	1.06
June 10	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.05	0.12	0.10	0.28	0.05	0.13	0.11	0.29
June 11	0.00	0.02	0.00	0.02	0.00	0.03	0.00	0.03	0.06	0.08	0.10	0.24	0.06	0.13	0.10	0.29
June 12	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.10	0.06	0.16	0.00	0.12	0.06	0.19
June 13	0.01	0.04	0.00	0.05	0.00	0.03	0.00	0.03	0.03	0.04	0.08	0.14	0.04	0.10	0.08	0.22
June 14	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.08	0.04	0.14	0.01	0.09	00.4	0.14
June 15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.02	0.09	0.01	0.05	0.02	0.09
June 16	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.00	0.03	0.03	0.05	0.00	00.5	0.03	0.08
June 17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.06	0.00	0.02	0.04	0.06
June 18	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.04	0.00	0.05	0.01	0.06	0.00	0.09	0.01	0.10
June 19	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.10	0.00	0.03	0.13	0.00	0.03	0.03	0.06
June 20	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.02	0.03	0.06	0.00	0.03	0.03	0.07
June 21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.07	0.00	0.04	0.03	0.07
June 22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
June 23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
June 24	0.00	0.04	0.01	0.06	0.00	0.01	0.00	0.01	0.00	0.01	0.04	0.06	0.00	0.07	0.06	0.13
June 25	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.02	0.09	0.00	0.11	0.02	0.11	0.00	0.13
June 26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
June 27	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.04	0.00	0.04
June 28	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.05	0.00	0.05	0.00	0.07	0.00	0.07
June 29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
June 30	0.22	0.00	0.00	0.22	0.00	0.22	0.00	0.22	0.00	0.44	0.22	0.67	0.22	0.67	0.22	1.11

[1]No fishing was permitted from April 29 to May 6.

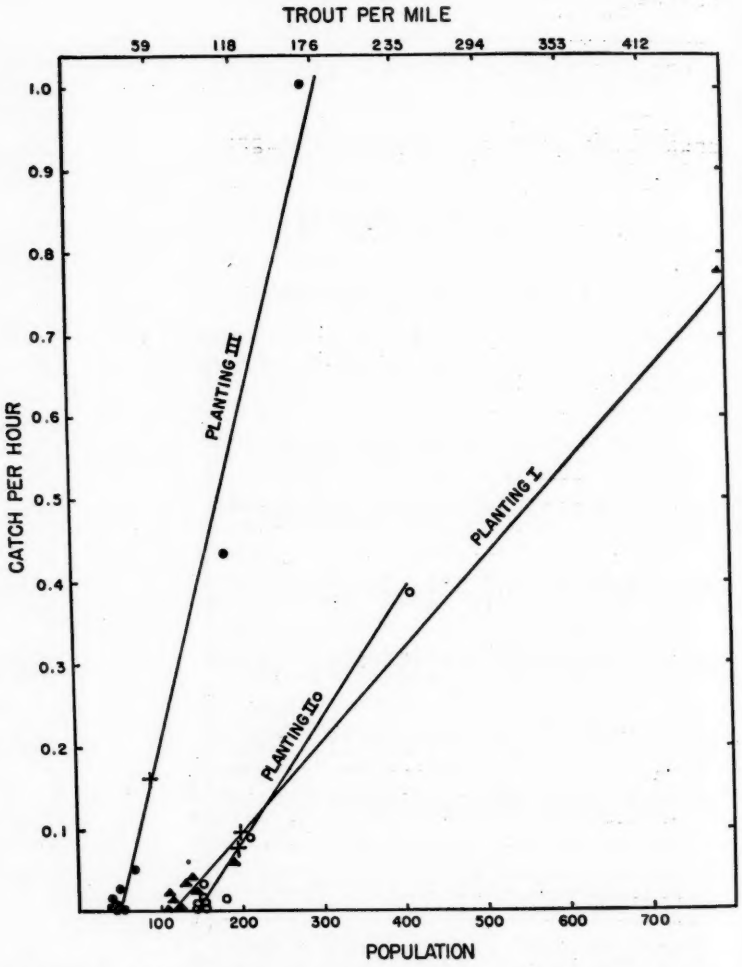

FIGURE 2.—Relationship between population and catch per unit effort for ten days following three plantings of marked brook trout, Blackledge River, 1942. + indicates mean.

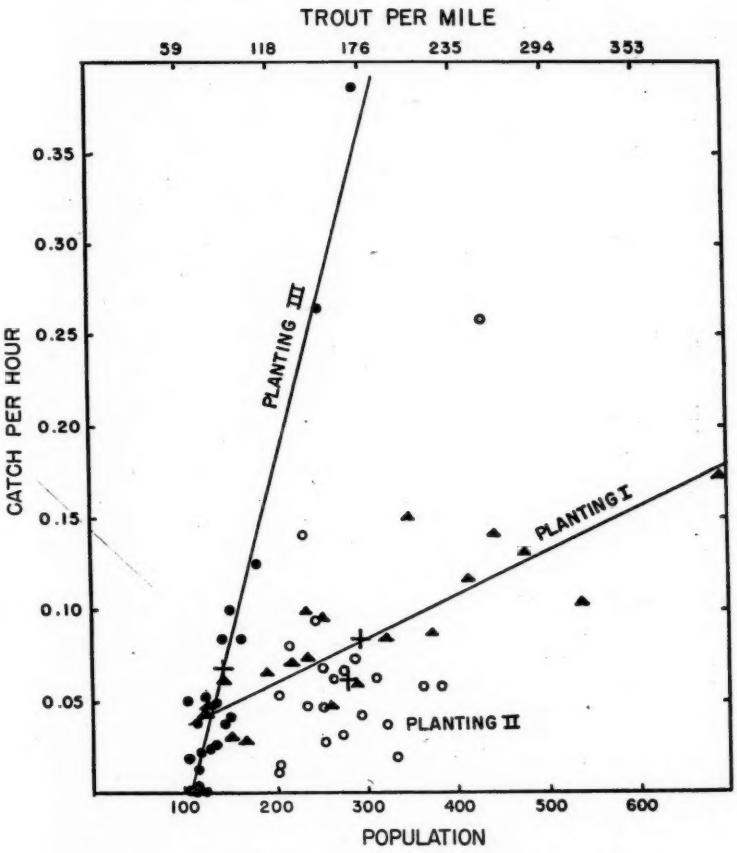

FIGURE 3.—Relationship between population and catch per unit effort for 21 days following three plantings of marked brown trout, Blackledge River, 1942. + indicates mean.

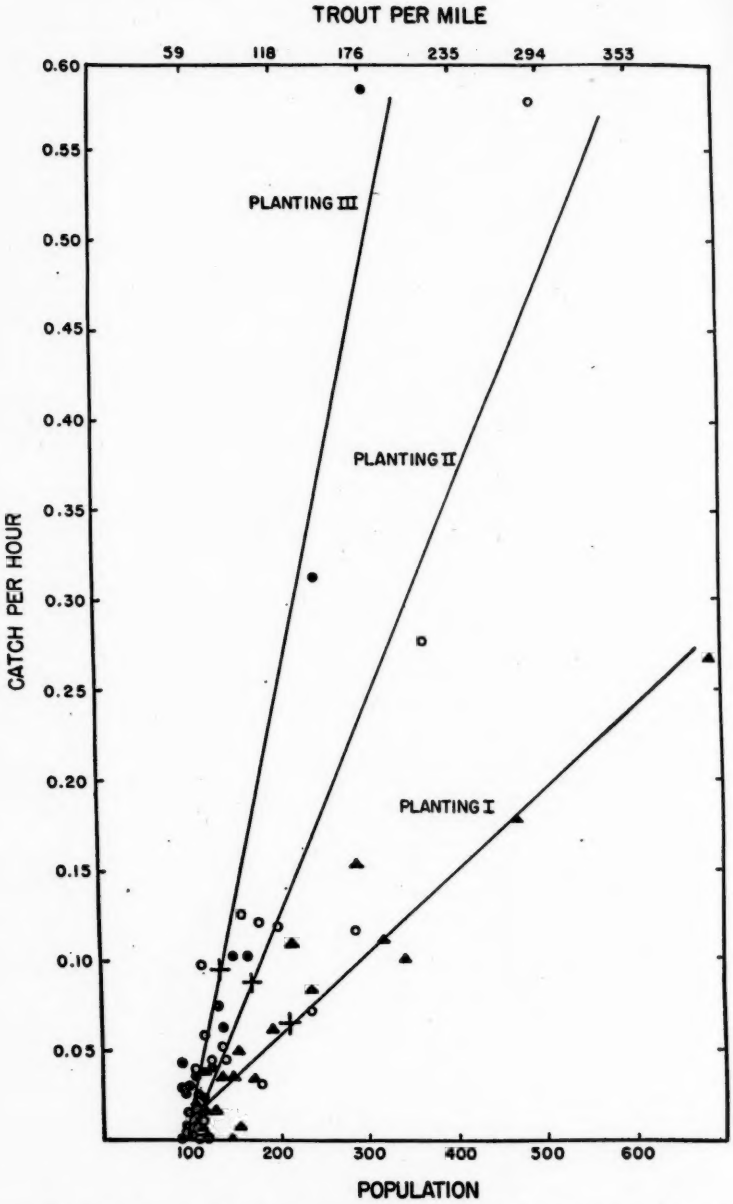

FIGURE 4.—Relationship between population and catch per unit effort for twenty-one days following three plantings of marked rainbow trout, Blackledge River, 1942. + indicates mean.

TABLE 8.—*Regression equations of population (X) and catch per hour (Y) in brook, brown, and rainbow trout in three plantings in the Blackledge River, 1942*

Planting	Brook trout	Brown trout	Rainbow trout
I	$Y = 0.00112X - 0.125$	$Y = 0.000242X + 0.0136$	$Y = 0.000458X - 0.0311$
II	$Y = 0.00147X - 0.285$	.....	$Y = 0.00119X - 0.112$
III	$Y = 0.00400X - 0.197$	$Y = 0.00184X - 0.191$	$Y = 0.00240X - 0.224$

In Planting II of brown trout, clearly the number of trout present shows little relation to the yield after the first day (May 7), and the writers conclude as did Schuck that factors other than number of trout present were important in determining yield in this instance. There is little doubt that this departure from the characteristic behavior observed in all other plantings was largely associated with the brown trout specifically used in this planting. Indication of this is given by the catch of brown trout from Planting I made during the same period. Consider the catch and effort data in Table 5 for Plantings I and II of brown trout, May 7 to 16. The brown trout in Planting II exhibit no relations to the amount of fishing effort as a correlation coefficient 0.24 shows. On the other hand, the correlation between effort and catch of brown trout in Planting I is significantly related ($r = 0.72$, just below the 1 per cent level of significance).

It is evident that this lot of newly planted brown trout responded differently to fishing pressure than did brown trout which had resided in the stream for a period of at least 3 weeks. Further investigation of similar behavior in newly planted trout and those from former plantings is rendered impossible by the fact that the population from one planting was virtually depleted when a new planting was made.

Most conspicuous in the relation between population and catch per unit effort in the three plantings is the apparent progressive increase in the slope in all three species (*i.e.*, regression coefficients). This means in effect that any given population gave a progressively higher yield per unit of effort in each planting. This observation is already prominent in the data in Table 7 for the initial days fishing following any one planting. It remains to test the significance of the several slopes (Snedecor, 1940, Sect. 6.17 using mean differences of the regression coefficients). The difference in slope between Plantings I and III in both brown and rainbow trout is highly significant. The significance in brook trout falls just short of the 5 per cent level; but in view of the behavior of the other species it seems likely that the observed slopes are of comparable interpretation and not chance variation. The slope in Planting II is intermediate in all instances.

It is impossible to interpret these observations satisfactorily from the present data, but three possibilities may be entertained:

1. The number of anglers fishing during any one planting decreased progressively through the season. For example, the total effort for the first 5 days following each planting was: Planting I, 722 anglers; Planting II, 456 anglers; Planting III, 238 anglers.

If there is a differential rate of capture between large and small efforts, this might result in observed seasonal increase in catch per unit effort. Since, however, the number of trout planted also was on a diminishing scale, it is unlikely that this is the case.

2. There is reason to believe that the skill of the "average" angler fishing in late season was greater than that in early season. If so, a greater catch per unit effort would be encountered. This is based on actual observations of anglers in the test area; late season anglers are usually more confirmed trout fishermen. There is no objective way of judging this from the present data.

3. There is good evidence, both from angling experience and from observations, that trout become increasingly active as the water temperature rises in the spring. The average water temperatures taken in the morning and afternoon for the first five days of fishing following each planting were as follows: Planting I, 52°F.; Planting II, 59°F.; Planting III, 68°F. It was noted on the Blackledge that the trout tended to congregate in the deeper holes during early spring and to move out into the riffles and fast water later in the season. This has been noted in a number of other situations by the authors. It is quite possible that the higher yields per unit of effort are the result of greater feeding activity on the part of the trout brought about by increases in water temperature. Of the three possibilities, this seems the most plausible.

There is some value in knowing whether or not the relation between population and catch per unit effort differs significantly among the species in the same planting. In two instances, brook and brown trout in Planting I and brown and rainbow trout, also in Planting I, the slopes differ significantly, the brown trout exhibiting a lower rate of capture for the available population. In Plantings II and III, there is no significant difference between the slopes. (This is not to be confused with differential rate of depletion which involves a time sequence.)

Distribution of Angler's Catch

The number of trout taken by each angler gives a clue as to the effectiveness and operation of creel limits. It further gives an idea of how the catch is being spread. The frequency of the number of anglers taking 0, 1, 2, 3 . . . 15 trout is given in Table 9. Information for each planting is broken down into the first and second day's fishing and the period following until the next planting. The data are reported as a percentage of the total number of anglers. These data are plotted in Figure 5. It is apparent that the distribution of the catch from the three plantings is essentially similar, and that the following general observations may be made:

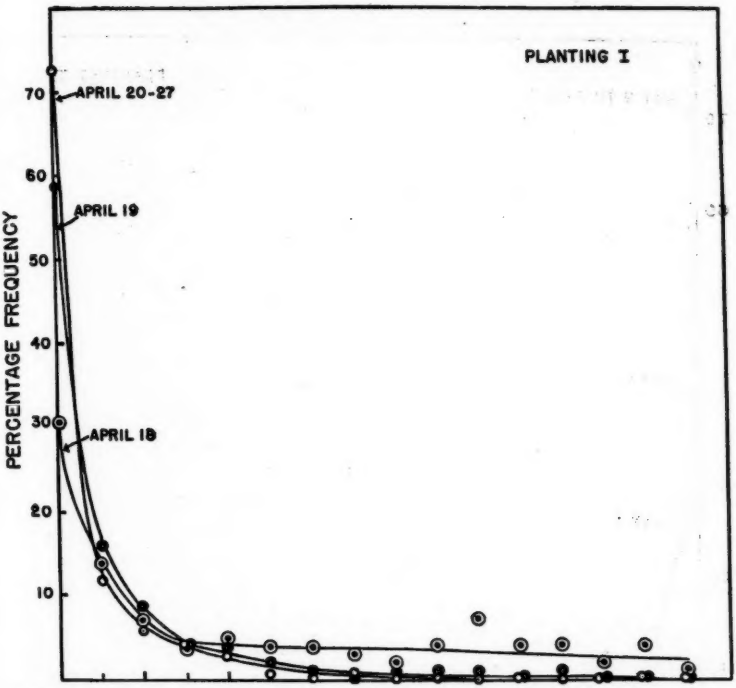

FIGURE 5a.—Percentage frequency of the number of marked trout caught per angler following Planting I, Blackledge River, 1942

TABLE 9.—*Distribution of the number of trout creeled per angler following each of the three plantings, Blackledge River, 1942. (Expressed as a percentage of the total number of anglers in each day or period)*

Number trout creeled	Planting I			Planting II			Planting III		
	April 18	April 19	April 20-April 29	May 7	May 8	May 9-June 7	June 8	June 9	June 10-June 30
0	31.4	58.8	73.0	27.8	43.8	74.9	23.1	37.0	72.7
1	13.6	17.2	11.9	11.1	13.5	12.7	20.5	10.9	17.1
2	6.8	8.6	6.0	6.9	11.5	5.4	5.1	12.0	5.6
3	4.1	4.5	4.1	13.9	9.4	3.2	7.7	12.0	2.8
4	5.0	4.1	2.7	5.6	0.0	1.6	5.1	5.4	0.5
5	3.6	2.3	0.7	4.2	6.2	0.8	0.0	4.3	0.5
6	3.6	0.9	0.2	5.6	3.1	0.4	2.6	3.3	0.0
7	2.7	0.0	0.6	6.9	6.2	0.2	0.0	2.2	0.0
8	1.8	1.4	0.2	4.2	3.1	0.5	2.6	3.3	0.2
9	4.1	0.9	0.1	4.2	1.0	0.1	0.0	2.2	0.2
10	7.3	0.9	0.2	4.2	0.0	0.0	5.1	1.1	0.2
11	4.1	0.0	0.1	0.0	1.0	0.0	2.6	3.3	0.0
12	4.1	0.4	0.0	1.4	0.0	0.0	2.6	0.0	0.0
13	2.3	0.0	0.0	1.4	1.0	0.0	7.7	0.0	0.0
14	4.1	0.0	0.0	1.4	0.0	0.0	5.1	2.2	0.0
15	1.4	0.0	0.0	1.4	0.0	0.0	10.2	1.1	0.0

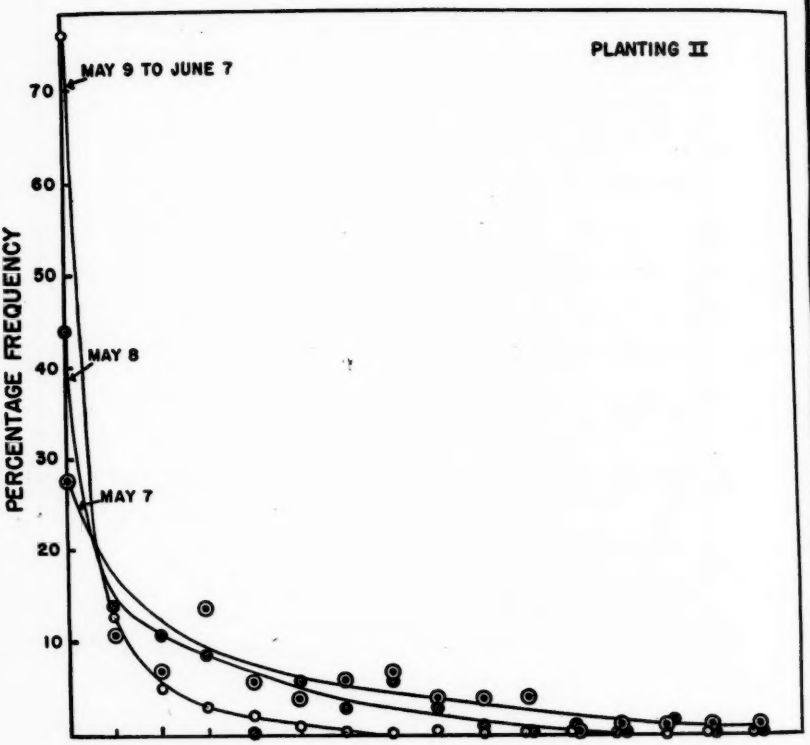

FIGURE 5b.—Percentage frequency of the number of marked trout caught per angler following Planting II, Blackledge River, 1942.

1. The frequency of anglers taking no trout was always highest, even with a dense population. After the second day's fishing the average number of anglers catching nothing was over 70 per cent.

2. A relatively small number of anglers accounted for a disproportionate fraction of the catch. For example, the number of anglers taking more than 5 trout during the first day of fishing is given in Table 10. About one-third of the anglers accounted for roughly three-quarters of the total catch.

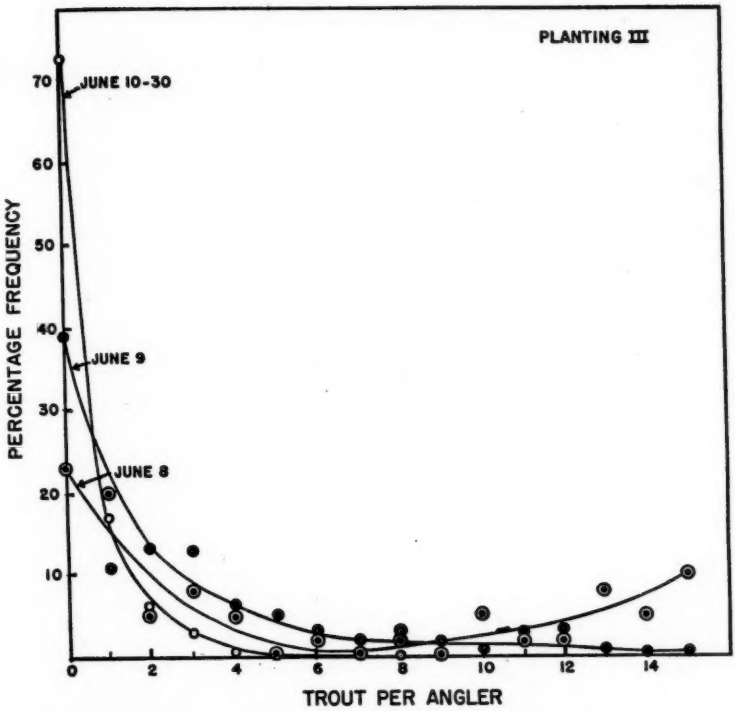

FIGURE 5c.—Percentage frequency of the number of marked trout caught per angler following Planting III, Blackledge River, 1942.

3. The most conspicuous shifts in distribution of the individual catch from any one plant are in the 0-class (increase) and in the classes above four trout (decrease). The frequencies of 1 to 4 fish remain by contrast, relatively constant. This is further brought out by data in Table 11.

It is probably true that a few anglers will generally account for a large proportion of the catch, for these undoubtedly represent the experienced and the skillful. With a 15 trout limit a considerable portion of a population may thus be removed shortly after planting. A lower limit might tend to spread the catch over a few more anglers and over a longer period of time.

TABLE 10.—*Anglers taking over five trout and relation to total catch in three plantings of trout, Blackledge River, 1942*

Planting	Percentage of anglers taking over five trout	Percentage of total catch
I	36	76
II	31	71
III	38	86

TABLE 11.—*Percentage of the total number of anglers taking 0, 1 to 4, and 5 to 15 trout following three plantings of trout, Blackledge River, 1942*

Number trout creeled	First day	Second day	Period until next planting
0	27	46	74
1 to 4	35	36	25
5 to 15	38	18	1

DISCUSSION

Under Connecticut conditions where trout fishing in the larger streams is provided almost solely by the stocking of legal-sized trout, there are two main objectives: To secure the maximum return from each planting and to spread its effects over as long a time interval as possible. In the Blackledge River experiments the recovery of about 80 per cent of the number of trout in each planting is certainly satisfactory. There is little doubt that the heavy fishing pressure encountered is directly responsible for the high returns. It is believed that the total anglers fishing this stream during the 1942 season was higher than it ordinarily would have been because of the publicity attending the experiment and because of an increased population due to nearby war industries. However, in spite of this and the fact that the 1933 tagging experiments indicated far lower yields, it is believed that this experiment exhibits the essential characteristics which are representative of trout fishing in Connecticut's State-leased or owned streams. This belief is based on observations over a large number of waters and the daily stream checking reports of fish and game wardens. The characteristics typical of Connecticut trout fishing are a high angling pressure following each planting of fish and a rapid depletion of the introduced population to a level where only poor fishing is produced. The rapid depletion is due to the distribution of angling pressure, and to a lesser extent, to the high creel limit. The reduction of the creel limit to say, 5 trout would undoubtedly help materially, but is certain far from the complete solution of the problem. It is, of course, impossible to regulate the distribution of angling pressure, in other than experimental ways. The only other possibility appears to be smaller and more frequent stockings of the stream. Reduction of the number of trout planted would lower the high initial yield, frequent stocking would increase the number of days of good fishing and probably tend to spread the effort somewhat.

The question also arises as to which species provides the most sus-

tained fishing. The conclusion derived from this experiment is quite obviously brown trout. Furthermore, the total seasonal yield is comparable to either brook or rainbow trout. The results of the Blackledge experiment are thus somewhat contradictory to those presented by Schuck (1942), who concludes that brook trout are more economical than brown trout to stock because of the higher total yield and the unpredictable results from stocking brown trout. It is possible that the apparent discrepancy is in part due to the marked difference in the total angling pressure between the two experiments and in part to the fact that trout in different sreams frequenly seem to behave quite differently.

The change in the relation between available population and the catch per unit effort also brings up problems with regard to predicting catch per unit effort from any given population or *vice versa*. Since any evidence for evaluating the observed change in rate of capture is confounded in this experiment, it would be desirable to investigate further the reasons for this.

Acknowledgment

Mr. Robert Moss, University of Connecticut, gave considerable assistance in the field work, as did also several members of the Warden Service. Members of the office staff of the Connecticut Board of Fisheries and Game made the original compilations and computations appearing in Tables 5 and 7. The senior authors were responsible for the field work, the junior author for the preparation of the manuscript.

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THE EFFECT OF NATURAL AND ARTIFICIAL PROPAGATION IN MAINTAINING A RUN OF ATLANTIC SALMON IN THE PENOBSCOT RIVER

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ABSTRACT

Analysis of the effect of hatchery plants of Atlantic salmon over a 70-year period on the maintenance of the Penobscot River salmon run shows that artificial propagation was not significantly more effective than natural propagation, but was more effective in later than in earlier years. The numbers that can be raised to a sufficiently large size before stocking to gain a material advantage over natural propagation are too limited to employ hatcheries for the maintenance of large runs. The chief role of the hatchery is to provide young fish for reestablishing former runs, and to increase the survival of young during the early period of restoration when the hatcheries can handle a significant proportion of the total eggs in the spawning run.

INTRODUCTION

On October 10, 1941, an agreement was signed by the Maine Department of Inland Fisheries and Game, the Maine Department of Sea and Shore Fisheries, and the U. S. Fish and Wildlife Service to insure the maximum utilization of facilities in the restoration of salmon runs in the State of Maine. A Salmon Research Committee was appointed to coordinate the work in artificial propagation and scientific fishery management, to promote increased biological research, and to recommend needed measures.

One of the first problems to consider was the present scarcity of Atlantic salmon in the Penobscot River. The great decline in abundance has been variously ascribed to overfishing, pollution, lack of adequate fishways, deforestation, and other causes. Certainly the knowledge of the events that have led to the present depleted condition of the runs is insufficient to point to any one cause, but conversely there is no reason to suppose that all of these factors have not played some part. The runs are now at such a low level that unless some adequate measures for their restoration are undertaken soon they may be expected to vanish from the Penobscot, as they already have disappeared from most New England rivers.

The first step in restoring the runs is to improve conditions for natural spawning. This entails two things—favorable conditions on the spawning beds and unobstructed passage up the river.

In some parts of New England the ecological conditions on the spawning beds have been so changed that there is serious doubt whether the streams are still suitable for salmon. This has been largely

the result of reduced stream flows and sedimentation of the gravel bars, formerly used for spawning, by deforestation and soil erosion. The chief spawning areas in the upper reaches of the Penobscot River, however, are in semi-wild forested country with a great scarcity of roads or trails, so that they have remained largely in their primitive condition.

The spawning gravels are of no value for salmon unless the fish can migrate from the sea to the spawning grounds, and from the spawning and nursery grounds to the sea unhampered by barriers of pollution or physical obstructions. Within the last 10 years the Department of Inland Fisheries and Game of the State of Maine has constructed large fishways at each of the dams on the main Penobscot. However, since they were built there has not been a salmon run of sufficient size to test their efficiency.

Pollution can form a barrier to migration by interposing a stretch of water which because of toxic pollutants or low oxygen content cannot be readily passed by the salmon. In the Penobscot River the chief sources of pollution are below the tributaries in which the salmon spawn and in which the young spend the first 2 years of their existence. The salmon must pass through the areas of heavy pollution during their migrations, but since both the up- and down-stream migrations in the main river occur chiefly during periods of high water when the pollutants are dilute it is not certain that pollution is one of the causes of depletion.

If a survey of the river should reveal pollution in such concentrations as might be harmful to fish life, then it may be necessary to test the resistance of salmon smolts to these concentrations, and to obtain data bearing on the length of time they probably would be exposed to dangerous pollution during their migration. The same may apply to the adult salmon on their upstream migration. Although it seems to be the general opinion that pollution is heavy between Bangor and Bucksport owing to pulpmill waste and sewage, it may be mentioned that the adult salmon taken each year in the trap at the Bangor Pool and held in the retaining pools at Craig Brook hatchery until their eggs are stripped in the autumn, show no apparent ill effects.

The second step in restoring the salmon runs, once there is assurance of proper ecological conditions, is to reverse the preponderance of mortality over the production of young. In the narrow estuary of the Penobscot above Sandy Point, it is possible to take a very heavy toll of salmon without much fishing gear. Considering the cost of fishways, pollution studies, propagation, and law enforcement necessary in the restoration of this run it would appear reasonable to prohibit or severely restrict fishing until the runs are wholly restored.

While prohibiting or restricting the commercial fisheries in the estuary of the river it would appear reasonable to prohibit the sale of Atlantic salmon caught by rod in areas prohibited to commercial fishermen, and to impose a seasonal bag limit on sportsmen.

With the salmon populations in the Penobscot at such an extremely low level it is important that the utmost be obtained from the limited spawning runs in terms of returning adults. Now, while the total run is so small, the hatcheries can handle a large proportion of the run. If their efficiency can be increased they can play an important role in restoration. Experiments are now being conducted to determine the best size and age at which to release young hatchery-reared salmon in order to obtain the maximum survival, measured by the number of returning adults.

These same experiments on survival in which hatchery fish are marked before being released, may provide the best answer to the question of the relative efficiency of natural and artificial propagation, when the numbers of adults returning from hatchery-raised fish are compared to the numbers returning from the spawning of a known number of adults counted in the fishways on their upstream migration to the spawning beds.

The greatest promise for obtaining larger returns from a given number of eggs, lies in improvement of hatchery techniques. In the past, few young salmon were ever held through the winter before release. It is hoped that a higher ultimate survival may be obtained by holding the fish until they attain a much larger size before stocking. These experiments have been hampered by certain difficulties in the way of diseases and what appears to be accumulative dietary deficiencies. The Fish and Wildlife Service is now studying special hatchery techniques including nutritional requirements of Atlantic salmon to overcome this hurdle.

The salmon of the Penobscot showed signs of declining numbers in the early part of the last century. In an attempt to maintain the runs, artificial propagation was commenced in 1870 and continued with practically no interruption to the present day, a period of over seventy years.

During the earlier years of operation only a limited number of fry were planted in the Penobscot River; the bulk of the eggs and fry were shipped to stock various streams and lakes throughout the eastern, southeastern and Great Lakes states. Since 1897 the bulk of the fry have been planted in the upper waters of the Penobscot and its tributaries. From 1897 to 1918, a period of 22 years, the records show an annual average of 1,729,000 fry and fingerlings planted in the Penobscot.

In spite of this stocking the runs declined to the point where it became difficult to obtain a sufficient number of adult salmon for stripping. In the space of 14 years, from 1919 until discontinued in 1936, 19,800,000 Atlantic salmon eggs were obtained from Canada, and nearly half of the resulting fry were planted in the Penobscot. The runs, however, continued to dwindle.

The annual stocking of the river has perhaps lulled many persons into a false sense of security. Even today more stocking of young

salmon is the panacea usually brought forth as the cure for the whole complex subject of salmon restoration. Even were artificial propagation many times more efficient than natural propagation it would be folly to expect it alone to overcome the drain of over-fishing plus the losses from other causes.

It may be possible through artificial propagation to attain significantly greater survival from the eggs handled than would be attained from natural spawning. However, the physical limitations on the total number of fish than can be hatched and reared to a size sufficiently large to obtain this increased survival, preclude the maintenance of large runs by hatcheries. Perhaps the chief role of the hatchery consists in providing young salmon for reseeding streams or tributaries from which salmon have disappeared, and in providing greater survival during the early period of restoration when the total run is very small.

This paper has been written to assess the contribution made by artificial propagation in maintaining the Penobscot River runs during seventy years of operations, as a guide to the future role of hatcheries in restoring salmon in New England.

Decline in Abundance of the Runs Since 1873

The take of salmon by the commerical fishery in the Penobscot River (Table 1 and Figure 1) has been compiled from various sources for 39 out of the 67 years from 1873 to 1939, inclusive. The commercial catch in the 5 years for which records are available in the 17-year period from 1873 to 1889 averaged 11,955 salmon, the lowest year, with 9,556 salmon, being higher than any year since. During the 25-year period from 1892 to 1916 the catch for the 22 years with available data averaged 4,838 salmon. During the 22-year period from 1918 to 1939 the catch for the 12 years available averaged but 2,472 salmon. The catch for 8 out of these 12 years was lower than the minimum catch of any of the previous 27 years for which statistics were compiled.

It is a well-known fact that the fishery has been prosecuted intensively throughout these years and that any major decline in the amount of gear fished (figures on gear are not available for most years) was due to the decline in the fishery. In the long narrow estuary of the Penobscot the competition between the different pound nets is such that even a very limited number of nets can take a large proportionate toll of the run. Therefore, it is safe to conclude that the figures show a tremendous decline in abundance. As will be shown later this conclusion is also borne out by the rod fishing at Bangor Pool.

As further proof of the present extreme scarcity, Raymond Dow stated in a resume of the 1939 season, "On the Penobscot River in 1939 eight salmon were taken at the Bangor Pool. A close check of

TABLE 1.—*Maine salmon catch, 1860 to 1940*

Year	Total Maine catch			Penobscot River catch (Hancock, Waldo Knox, & Penobscot Counties)		Average weight of Penobscot salmon					Penobscot River No. of salmon			
	U.S. Bureau of Fisheries	U.S. Census Bureau	State of Maine	U.S. Bureau of Fisheries	State of Maine	From Atkins[1]	From Smith[2]	From Fishery Industry[3]	From Hatchery observations	Empirical	Observed	Calculated from weights from U. S. figures	Calculated from weights from State of Maine figures 1906-1916	Observed and calculated
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Number*	*Number*	*Number*	*Number*
1940	.....	.....	.....	.....	.....	.....	.....	.....	10.2	.....	.....	.....	.....	.....
1939	2,100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1938	15,700	.....	.....	10,600	.....	.....	.....	.....	11.0[4]	.....	.....	964	.....	964
1937	24,200	.....	.....	13,400	.....	.....	.....	.....	.....	10.5	.....	1,276	.....	1,276
1936	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1935	39,400	.....	.....	15,300	.....	.....	.....	.....	.....	10.5	.....	1,457	.....	1,457
1934	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1933	24,644	.....	.....	12,916	.....	.....	.....	.....	.....	10.5	.....	1,230	.....	1,230
1932	36,125	.....	.....	.....	.....	.....	.....	.....	.....	10.5	.....	2,403	.....	2,403
1931	70,190	.....	.....	58,012	.....	.....	.....	.....	.....	10.5	.....	5,525	.....	5,525
1930	88,295	.....	.....	75,794	.....	.....	.....	.....	.....	10.5	.....	7,218	.....	7,218
1929	43,554	.....	.....	40,039	.....	.....	.....	.....	.....	10.5	.....	3,813	.....	3,813
1928	14,747	.....	.....	12,700	.....	.....	.....	.....	.....	10.5	.....	1,210	.....	1,210
1927	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1926	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1925	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1924	12,348	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1923	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1922	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1921	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1920	.....	.....	.....	15,135	.....	.....	.....	9.5	.....	.....	1,598	.....	.....	1,598
1919	20,610	.....	.....	13,557	.....	.....	.....	10.3	.....	.....	1,322	.....	.....	1,322
1918	.....	.....	.....	17,212	.....	.....	.....	10.4	.....	.....	1,653	.....	.....	1,653
1917	.....	.....	.....	.....	.....	.....	.....	.....	.....	10.5	.....	.....	.....	.....
1916	.....	.....	64,326	.....	59,320	.....	.....	.....	.....	10.7	.....	.....	5,544	5,544
1915	.....	.....	.....	.....	.....	.....	.....	.....	.....	10.8	.....	.....	.....	.....
1914	.....	.....	83,146	.....	54,006	.....	.....	.....	.....	11.0	.....	.....	4,910	4,910
1913	.....	.....	84,315	.....	78,960	.....	.....	.....	.....	11.2	.....	.....	7,050	7,050
1912	.....	.....	151,070	.....	86,240	.....	.....	.....	.....	11.4	.....	.....	7,565	7,565
1911	.....	.....	147,799	.....	98,680	.....	.....	.....	.....	11.6	.....	.....	8,507	8,507
1910	.....	.....	62,669	.....	56,738	.....	.....	.....	.....	11.8	.....	.....	4,808	4,808
1909	.....	.....	28,388	.....	26,125	.....	.....	.....	.....	12.0	.....	.....	2,177	2,177
1908	.....	19,000	36,605	.....	33,425	.....	.....	.....	.....	12.2	.....	.....	2,740	2,740
1907	.....	.....	40,881	.....	32,295	.....	.....	.....	.....	12.3	.....	.....	2,626	2,626
1906	.....	.....	56,066	.....	41,202	.....	.....	.....	.....	12.5	.....	.....	3,296	3,296
1905	86,298	.....	65,044	74,157	52,368	.....	.....	11.6	.....	.....	6,378	.....	.....	6,378
1904	.....	.....	63,428	63,395	55,272	.....	.....	13.3	.....	.....	4,776	.....	.....	4,776

1904	.....	.....	63,428	63,595	55,272	.....	.....	11.6 13.3	.....	.....	6,378 4,776	.....	.....	6,378 4,776
1903	.....	.....	42,247	67,470	36,471	.....	.....	13.9	.....	.....	4,859	.....	.....	4,859
1902	60,768	.....	39,935	45,782	.....	.....	.....	14.0	.....	.....	3,269	.....	.....	3,269
1901	.....	.....	96,891	86,055	.....	.....	.....	12.6	.....	.....	6,801	.....	.....	6,801
1900	.....	.....	44,213	44,660	32,303	.....	.....	12.6	.....	.....	3,541	.....	.....	3,541
1899	.....	.....	55,014	45,688	40,776	.....	.....	13.0	.....	.....	3,515	.....	.....	3,515
1898	53,322	.....	33,869	42,280	32,418	.....	.....	13.2	.....	.....	3,225	.....	.....	3,225
1897	.....	.....	.....	51,522	.....	.....	.....	12.9	.....	.....	3,985	.....	.....	3,985
1896	.....	.....	.....	80,225	.....	.....	13.2	12.5	.....	.....	6,403	.....	.....	6,403
1895	.....	.....	.....	65,011	.....	.....	15.9	14.8	.....	.....	4,395	.....	.....	4,395
1894	.....	.....	.....	.....	.....	.....	13.2	.....	.....	.....	.....	.....	.....	.....
1893	.....	.....	.....	.....	.....	.....	13.6	.....	.....	.....	.....	.....	.....	.....
1892	138,322	.....	.....	92,282	.....	.....	15.2	.....	.....	.....	.....	6,071	.....	6,071
1891	.....	.....	.....	.....	.....	.....	10.3	.....	.....	.....	.....	.....	.....	.....
1890	.....	.....	.....	.....	.....	.....	15.6	.....	.....	.....	.....	.....	.....	.....
1889	.....	152,740	.....	140,469	.....	.....	14.9	.....	.....	.....	.....	9,556	.....	9,556
1888	205,149	.....	.....	192,177	.....	.....	13.8	.....	.....	.....	.....	13,926	.....	13,926
1887	185,637	.....	.....	169,894	.....	.....	13.5	.....	.....	.....	.....	12,585	.....	12,585
1886	.....	.....	.....	.....	.....	.....	16.3	.....	.....	.....	.....	.....	.....	.....
1885	.....	.....	.....	.....	.....	.....	12.1	.....	.....	.....	.....	.....	.....	.....
1884	.....	.....	.....	.....	.....	.....	9.6	.....	10.0	.....	.....	.....	.....	.....
1883	.....	.....	.....	.....	.....	.....	16.8	.....	18.0	.....	.....	.....	.....	.....
1882	.....	.....	.....	.....	.....	.....	11.1	.....	13.0	.....	.....	.....	.....	.....
1881	.....	.....	.....	.....	.....	.....	17.5	.....	16.6	.....	.....	.....	.....	.....
1880	.....	111,324	.....	110,176	.....	.....	12.9	.....	13.0	.....	.....	10,016	.....	10,016
1879	.....	.....	.....	.....	.....	.....	12.0	.....	12.3	.....	.....	.....	.....	.....
1878	.....	.....	.....	.....	.....	.....	13.5	.....	.....	.....	.....	.....	.....	.....
1877	.....	.....	.....	.....	.....	.....	13.9	.....	.....	.....	.....	.....	.....	.....
1876	.....	.....	.....	.....	.....	.....	15.1	.....	.....	.....	.....	.....	.....	.....
1875	.....	.....	.....	.....	.....	.....	13.0	.....	.....	.....	.....	.....	.....	.....
1874	.....	.....	.....	.....	.....	.....	14.6	.....	14.0	.....	.....	.....	.....	.....
1873	.....	.....	.....	.....	.....	10.5	.....	.....	13.3	.....	13,690[5]	.....	.....	13,690
1872	.....	.....	.....	.....	.....	13.2	.....	.....	12.3	.....	.....	.....	.....	.....
1871	.....	.....	.....	.....	.....	13.2	.....	.....	.....	.....	.....	.....	.....	.....
1870	.....	.....	.....	.....	.....	12.5	.....	.....	.....	.....	.....	.....	.....	.....
1869	.....	.....	.....	.....	.....	12.0	.....	.....	.....	.....	.....	.....	.....	.....
1868	.....	.....	.....	.....	.....	12.1	.....	.....	.....	.....	.....	.....	.....	.....
1867	.....	.....	.....	.....	.....	11.4	.....	.....	.....	.....	.....	.....	.....	.....
1866	.....	.....	.....	.....	.....	11.0	.....	.....	.....	.....	.....	.....	.....	.....
1865	.....	.....	.....	.....	.....	11.2	.....	.....	.....	.....	.....	.....	.....	.....
1864	.....	.....	.....	.....	.....	12.1	.....	.....	.....	.....	.....	.....	.....	.....
1863	.....	.....	.....	.....	.....	9.8	.....	.....	.....	.....	.....	.....	.....	.....
1862	.....	.....	.....	.....	.....	12.1	.....	.....	.....	.....	.....	.....	.....	.....
1861	.....	.....	.....	.....	.....	12.3	.....	.....	.....	.....	.....	.....	.....	.....
1860	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

[1]Charles G. Atkins (1874) Salmon from two weirs on Verona Island.
[2]Hugh M. Smith (1898) Salmon from two weirs on Verona Island.
[3]From Fishery Industry of the United States, U. S. Bureau of Fisheries.
[4]From manuscript of Raymond W. Dow.
[5]Atkins (1874), p. 313.

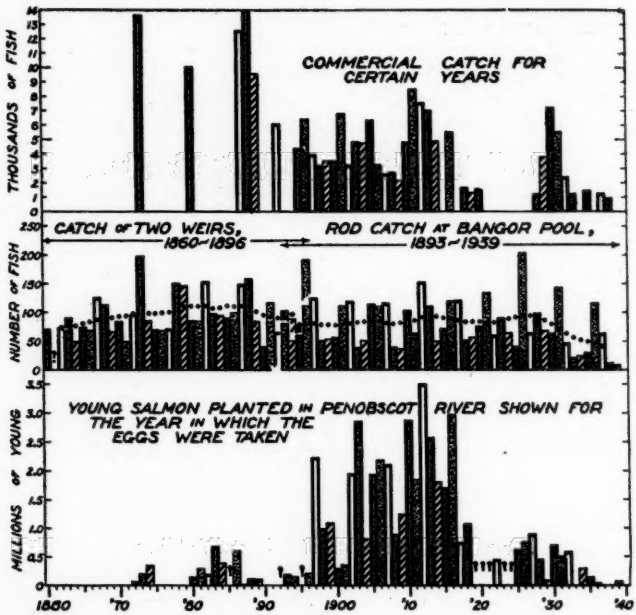

FIGURE 1.—Upper—Commercial catch of Atlantic salmon in the Penobscot River and its estuary (see Table 1).

Middle—The catch of salmon by two weirs on Verona Island, 1860-1896 (see Table 2); and the catch by sportsmen at Bangor Pool, 1893-1939.

Lower—Showing numbers of young Atlantic salmon planted in the Penobscot River according to the year in which the eggs were taken.

the fish markets and the weir operators indicates that not over fifty were taken in commerical fisheries."

In 1940 Federal officials decided to resume the taking of adult Penobscot salmon for artificial propagation, a practice discontinued after 1922. However, instead of using the former rather unsatisfactory practice of buying salmon from the weir operators, a trap was installed at the head of the large fish ladder in the Bangor dam. The first salmon was caught on June 6 and the last on October 5. Altogether only 104 salmon were trapped. This presumably represented the bulk of the run, but a few were seen to leap the dam, and the number thus bypassing the trap is unknown.

During the 1943 season, approximately 40 salmon were taken by pound nets in the estuary of the Penobscot, according to Lester A. Stubbs, warden of the Maine Department of Sea and Shore Fisheries.

The sport catch at Bangor Pool was 5 salmon. The hatchery at Craig Brook trapped 54 salmon in the fishway at Bangor Dam for use in propagation, and one salmon, which probably leaped Bangor Dam, was taken in a trap maintained in the fishway at Veazie Dam by the Inland Fisheries and Game Department. Veazie Dam is impassable to salmon except by means of the fish ladder which was trapped in order to obtain a certain count of the run. Thus the total 1943 run to the Penobscot was approximately 100 salmon!

Cyclic Character of the Runs

Comparison of the Commercial Catch and the Rod Catch at Bangor Pool, 1893-1939

In addition to the commercial catch data, the catch by the Penobscot Salmon Club at the Bangor Pool is available from 1893 to 1939, a period of 47 years. (See figure 1).

The Bangor Pool is the name applied to the section of the main river immediately below the low dam at Bangor. The river below the dam rises and falls several feet with each tide. The dam may be passable to salmon on high stages of the tide without use of the fish ladder when sufficient water is flowing over the spillway. The flood of 1922 washed out the fishway which was replaced in 1923 by another fishway, generally regarded as unsatisfactory.

After 1923 the anglers' catch showed an abrupt rise which Raymond Dow (unpublished manuscript) explains by stating:

> The building of a supposedly impassable fishway at the Bangor Dam in 1923 probably had a tendency to hold the salmon in the pool, which may account for the increased rod catch in the years that followed.

A new fishway was constructed at Bangor Dam in the fall of 1936.

Because commercial catch data are not available for many of the years, the commercial and rod catches were compared to determine whether or not the rod catches showed the same relative changes in size from year to year as the commercial catch, so that they could be used in studying these annual changes. (See Appendix for methods). The rod catches and the commercial catch showed a high significant correlation, so that the rod catches have been used for studying cyclic changes in the run.

5-Year Cycle in the Rod Catches, 1893-1939

In the Penobscot River the majority of the salmon attain maturity and spawn five years from the time the eggs producing them were deposited in the gravel, according to Dow, who said:

> A collection of scales taken during one of the peak years (1936) indicated the great majority of the fish were four years old. Such fish require five years to effect a return of their kind.

In order to test this point the adjusted rod catch for each year was correlated with the catch made 5 years later. The resultant correla-

tion coefficient of +0.66 is significant; the probability that it is due to chance being less than 1 in 100.

The relationship between the rod catch of one year and the catch 5 years later is somewhat obscured, however, by changes in the general level of abundance during this period. This effect was removed by smoothing the adjusted rod catches twice by a moving average of 5's and then expressing the annual deviations from this norm as percentages of the norm. The correlation of the percentage deviation of each year from the norm with the deviation 5 years later gave a distinctly higher coefficient of correlation of +0.72.

The degree to which the rod catch of one year influences the catch five years later is indicated by the square of the correlation coefficient called the coefficient of determination (Ezekiel, 1930). This value is 0.52, indicating that over 50 per cent of each year's variation in rod catch can be accounted for by the size of the rod catch made five years before. In order to obtain such a high degree of association it is necessary to assume a close relationship between the rod catch each year and the number of fish escaping to the spawning grounds.

Thus in the Fraser River, in British Columbia, the sockeye salmon are predominantly 4 years of age at maturity (instead of 5 years as for the Atlantic salmon of the Penobscot). Correlation of the index of abundance each year with the index of abundance 4 years later for the period of 39 years from 1896 to 1934 (Rounsefell and Kelez, 1938, page 772) gives a coefficient of correlation of 0.88. The coefficient of determination of 0.78 indicates that 78 per cent of each year's variation in abundance is dependent on the abundance present four years previously.

Since the index of abundance for the Fraser River sockeyes was calculated from a tremendous mass of data and represents catch per unit of fishing effort, it is undoubtedly a more reliable measure of abundance and less subject to sampling error than the Bangor Pool rod catch. The high correlation obtained for the 5-year cycle in rod catches would tend to indicate that the 5-year cycle may be more pronounced than can be demonstrated by the data.

Cycles in the Weir Catches, 1860-1896

Relationship of catch and average weight in the Verona Island weir catches

The catch of two weirs on Verona Island at the mouth of the Penobscot is given by Charles G. Atkins (1874) from 1860 to 1873. (See Table 2). Hugh M. Smith (1898) gives the catch of two Verona Island weirs from 1874 to 1896. The data given by Smith do not appear to represent the catches of the same two weirs used by Atkins as there is an immediate and abrupt change in the level of the catches reported in the second series. There is also an abrupt change in the

TABLE 2.—*Salmon caught in the Penobscot River by two weirs on Verona Island and by sportsmen of the Penobscot Salmon Club in Bangor Pool*

Year	Catch of two weirs on Verona Island		Rod catch at Bangor Pool		Year	Rod Catch at Bangor Pool	
	Actual (fish)	Adjusted (fish)	Actual (fish)	Adjusted (fish)		Actual (fish)	Adjusted (fish)
1860	161	71	.....	.....	1901	112	.....
61	.....	.....	.....	.....	02	120	.....
62	165	73	.....	.....	03	39	.....
63	207	91	.....	.....	04	51	.....
64	111	49	.....	.....	1905	115	.....
1865	168	74	.....	.....	06	111	.....
66	157	69	.....	.....	07	117	.....
67	288	127	.....	.....	08	39	.....
68	257	113	.....	.....	09	37	.....
69	151	67	.....	.....	1910	103	.....
1870	193	85	.....	.....	11	64	.....
71	112	49	.....	.....	12	153	.....
72	219	97	.....	.....	13	111	.....
73	449	198	.....	.....	14	50	.....
74	86	.....	.....	.....	1915	72	.....
1875	70	.....	.....	.....	16	120	.....
76	68	.....	.....	.....	17	121	.....
77	72	.....	.....	.....	18	52	.....
78	151	.....	.....	.....	19	57	.....
79	147	.....	.....	.....	1920	76	.....
1880	86	.....	.....	.....	21	134	.....
81	85	.....	.....	.....	22	60	.....
82	154	.....	.....	.....	23	90	.....
83	98	.....	.....	.....	24	111	64
84	95	.....	.....	.....	1925	72	41
1885	91	.....	.....	.....	26	354	204
86	100	.....	.....	.....	27	112	64
87	150	.....	.....	.....	28	170	98
88	159	.....	.....	.....	29	119	68
89	85	.....	.....	.....	1930	111	64
1890	41	.....	.....	.....	31	248	143
91	117	.....	.....	.....	32	82	47
92	65	.....	.....	.....	33	36	21
93	102	.....	81	.....	34	41	24
94	88	.....	51	.....	1935	52	30
1895	75	.....	61	.....	36	203	117
96	192	.....	112	.....	37	110	63
97	.....	.....	125	.....	38	20	12
98	.....	.....	51	.....	39	8	8
99	.....	.....	53	.....			
1900	.....	.....	57	.....			

reported weights of the individual fish (Table 1) which tends to support the assumption that these two series of data were derived either from different weirs or in a different manner. The earlier data have been adjusted to the level of the latter series by the factor 0.4412 (Table 2, column 3, and figure 1). This is derived by taking the average of the per cent that the catch of each of the last five years of the earlier series is of the catch five years later in the second series, thus making allowance for a different level of abundance in each 5-year cycle.

Both Atkins and Smith give the average weight of the individual salmon in the catches of the Verona Island weirs. In these average weights, as in the catches, there is an abrupt change between the two series. For the 23 years from 1874 to 1896 the weight averaged 13.81 pounds per fish, while in the 13 earlier years it averaged but 11.80

pounds. The earlier series was increased by the factor 1.1703 (or $\frac{13.81}{11.80}$) to place the two series on a comparable basis.

For the 36-year period, 1860-1896, the percentage deviations of the adjusted weir catches from the trend (adjusted catches smoothed twice by 5's) were correlated with the average weight of the individual salmon. This showed a negative correlation between the catch and the weight of the individual fish of —0.4277 (P of just over 0.01). Why there should be a negative correlation between the sizes of the salmon run (as reflected in the weir catches) and the average weight of the salmon is not clear unless one assumes that in these earlier years more than one age group of salmon was present in fair numbers in the catch. Thus in a year when the catch was composed chiefly of 6-year old fish the weight of the individual fish would be high, but the scarcity of the presumably smaller, but relatively more abundant 5-year old fish would mean a lowered catch. The presence of more 6-year old fish in the earlier years is borne out below by an analysis of the cycles present in the catches at that time.

The Verona Island weir catches from 1860 to 1896 (Table 2) do not exhibit as marked cycles as do the rod catches of later years. The 5-year cycle shows a correlation coefficient of +0.41, the 6-year cycle +0.34. The coefficient of determination indicates that the 5-year cycle had a 17 per cent influence on the catch and the 6-year cycle a 12 per cent influence, or a total influence of 29 per cent. This compares to a 52 per cent influence of the 5-year cycle in the rod catches of later years. The lesser association in the weir catches may be due to a greater amount of random variability in weir catches than in the rod catches.

Cycles in Combined Weir and Rod Catch Data, 1860-1939

When the deviations in catch from the trend of both weir and rod catches for the whole 80 years from 1860 to 1939 are analyzed for cycles, it is found that the correlation coefficient for five-year cycles is +0.61. For 6-year cycles the coefficient is +0.03 and not significant. Likewise, there is no significance to the coefficient of —0.16 for 4-year cycles. The heavier weight of the individual salmon in the earlier years gives evidence that the 6-year cycle was not an artifact, but actually due to the presence of significant numbers of older (and heavier) fish in the catches. What has caused the decrease in the relative numbers of these older fish?

Possibly it is due to the failure of natural reproduction, through pollution or obstructions, in some of the upriver spawning grounds. On many salmon rivers the smolts in certain tributaries, usually those tributaries least suitable for the making of rapid growth, remain a longer time in fresh water before descending to the sea. On a large river system, such as the Penobscot, it is unlikely that all of the main

tributaries present equally favorable growth conditions. Therefore, the failure of a portion of the tributaries might easily change the age composition of the run.

Efficiency of Artificial Propagation

Before attempting to assess the contribution of artificial propagation towards the maintenance of the salmon runs it would be well to examine the records to see what the hatcheries have been able to accomplish in the way of increasing the numbers of fry by artificial methods over the numbers produced through natural spawning. In the past some ardent proponents of artificial propagation have ascribed an efficiency of 90 per cent to the hatcheries compared to 10 per cent by natural methods. No acceptable proof of such statements has been offered.

Records of the Federal hatchery on the Penobscot River, which has operated since 1870 (except for the period 1875-78) are not complete for all years, and more complete information is available for some years than for others. However, from the records that have been compiled it is possible to estimate roughly the total efficiency of the hatchery in terms of fry planted.

There are three sources of loss between the adult and the fry planted in the river. The first loss is in the mortality of the adults which are held in retaining ponds from the time of their capture while migrating upstream in the late spring and early summer until they are stripped in the fall. A second loss is in the number of eggs that cannot be expressed in stripping the female salmon. The third loss is in the hatching and the rearing of the fry up to the time of planting.

There was a progressive improvement in efficiency between the earlier period of operation of the hatchery and the period when the capture of salmon was supplanted by the importation of Canadian eggs following 1922. From 1872 to 1910 the survival of adult salmon in the retaining ponds, based on 22 years data, was 69.9 per cent. From 1911 to 1922 the survival, based on 6 years data, was raised to 85.1 per cent.

The loss of eggs from stripping Atlantic salmon is not known. For sockeye salmon, Foerster (1936a) found in 151 specimens examined during 1931 and 1932, that 14.5 per cent of the eggs were left in the female during stripping. He further discovered that when the stripped females were permitted to spawn these remaining eggs naturally 77 per cent of them hatched and developed. Therefore, the minimum loss of sound eggs in stripping was 11.2 per cent (77 per cent of 14.5 per cent).

The records available do not show separately the survival of the eggs during incubation and the survival of fry up to the time of planting. The combined survival from the time of the taking of the eggs

until the planting of the fry averaged 89.0 per cent in 8 years between 1911 and 1921.

The total efficiency of the hatchery during the period 1872-1910 can be calculated as 69.9 per cent survival of adults plus an additional 11.2 per cent estimated loss of sound eggs in stripping or 62.1 per cent multiplied by 89.0 per cent survival from eggs to fry, or a total efficiency of 55.3 per cent. A similar calculation for the 1911-22 period gives a total efficiency of 67.3 per cent.

Accurate figures for sockeye salmon propagation at Cultus Lake hatchery (Foerster 1936b) show (for the 3 years of 1926, 1929 and 1932) an average survival from the total number of eggs available in the adult salmon up to the time of fry planting of 63.2 per cent. This compares closely with the 67.3 per cent efficiency calculated for the Penobscot hatchery during the latter years.

The efficiency of hatchery propagation in terms of survival of the young does not by itself constitute any measure of its success. That can only be finally judged by comparing this efficiency with that obtained from natural propagation. No direct evidence bearing on this question is available for Atlantic salmon, but certain indirect evidence will be examined in the next section. For sockeye salmon (Foerster 1936) careful scientific observations over several years showed that the proportion of young salmon surviving in the lake to the age where they migrate to sea was not significantly higher when the adults were stripped, the eggs incubated in the hatchery, and the young planted as fry, than it was when the adults were permitted to spawn naturally.

However, one must not lose sight of the fact that although the Cultus Lake experiments on sockeye salmon indicate that no significant advantage in survival over natural spawning is gained by merely incubating the eggs and planting the fry at an early stage, this in itself is not an indictment of artificial propagation. Thus experiments at Cultus Lake (Foerster 1938) showed that the loss of young salmon in the lake was very much higher in the first few months than later. By retaining young salmon for several months after hatching it may be possible to avoid much of this heavy loss.

Evidence of this heavy initial loss is shown also by Kelez (Rounsefell and Kelez, 1938) for a second species of salmon. He marked and released 26,000 young coho salmon averaging 47.4 millimeters in length at the Samish hatchery in the spring of 1934. An additional 26,000 young cohoes from the same lot of brood fish were marked and liberated in November at an average length of 101.6 millimeters. From the first lot only 7 marked adults returned from the sea, but the second lot yielded 462 adults.

Relative Effect of Natural and Artificial Propagation in Maintaining the Run

Natural spawning has presumably occurred every year in the Penobscot River so that the effects of natural and artificial propagation

cannot be considered separately. In attempting to determine the role played by artificial propagation the first question that occurs is what proportion of the total number of eggs contained in the adults of each year's run has been handled by the hatchery and what proportion has been deposited by natural spawning.

It is possible to arrive at a fairly close estimate of the number of eggs required by the hatchery to produce the young salmon planted in the Penobscot (disregarding the loss of adults in the retaining ponds, and the loss of sound eggs in stripping) from the data on the numbers of fry and fingerlings planted. It is necessary to calculate the number of eggs, as for many of the years the actual number taken is not available, and for other years a portion of the eggs or fry have been shipped or planted elsewhere than in the Penobscot. As calculations (see Table 3) for years in which the number of eggs is known indicate an 89.0 per cent survival from eggs to fry and a 49.9 per cent survival from eggs to fingerlings, it was possible to calculate the number of eggs required to produce the plants of young salmon, by multiplying the fry plants by the factor 112.3 and the fingerling plants by 200.4.

No such accurate estimate of the amount of natural spawning is possible, but it is possible to make an estimate that although admittedly subject to criticism gives an idea of the relative magnitude of natural versus artificial propagation.

Assuming that 50 per cent of the salmon in each year's run escaped to the spawning grounds, the number escaping would equal the number caught. As the rod catch (adjusted) appears to be more representative of the relative abundance than the commercial catch, as well as covering a continuous series of years, it has been used to represent the size of the run by multiplying it by 45.45 (as the rod catch was shown earlier to average 2.2 per cent of the commercial). This estimated number of salmon escaping to the spawning grounds was now converted to pounds by the weights shown in Table 1. Over a 12-year period the number of eggs per pound of female salmon averaged 698. Therefore, allowing 50 per cent females the number of pounds of salmon spawning was multiplied by 349 (one-half of 698) to obtain an estimate of the total number of eggs available for natural spawning.

For the 35 years between 1893 and 1934 for which the number of eggs needed by the hatchery to produce the young salmon planted could be calculated, the number of hatchery eggs averaged 10.9 per cent of the number estimated to have been spawned naturally. Between 1893 and 1918, the average for 25 years with data was 13.0 per cent and from 1922 to 1934 the average for 10 years was 5.7 per cent. Even though the estimate of the number of eggs spawned naturally may be considerably in error, yet it is still several times greater than the number used for artificial propagation.

Obviously then, artificial propagation, in order to have any pronounced effect, needs to be several times as efficient as the natural.

TABLE 3.—*Propagation of Atlantic salmon on the Penobscot River 1872 to 1941*

Year eggs were taken	Number of adult salmon						Number of eggs		Number of eggs (000 omitted)			Salmon planted (000 omitted)		Percentage survival		Young salmon planted in Penobscot River system[1] (000 omitted)
	Number held	Number survived	Number females stripped	Per cent of adults surviving		Calculated number held	Per female stripped	Per pound of female	Total stripped	Received from Canada	Eggs incubated at hatchery	Fry	Fingerlings	From eggs to planted fry	From eggs to planted fingerlings	
				Observed	Empirical											
1941	.....	.....	40	.....	.....	.....	.....	.....	262	.....	.....	.....	.....	.....	.....	.....
1940	104	84	44	.....	.....	.....	.....	.....	246	51	.....	.....	.....	.....	.....	.....
1939	25	16	11	.....	.....	.....	.....	.....	113	0	.....	.....	91	.....	.....	69
1938	0	.....	0	.....	.....	.....	.....	.....	0	0	.....	.....	.....	.....	.....	0
1937	0	.....	0	.....	.....	.....	.....	.....	0	0	.....	.....	.....	.....	.....	0
1936	0	.....	0	.....	.....	.....	.....	.....	0	71	.....	.....	.....	.....	.....	41
1935	0	.....	0	.....	.....	.....	.....	.....	0	1,470	.....	.....	.....	.....	.....	139
1934	0	.....	0	.....	.....	.....	.....	.....	0	1,000	.....	184	.....	.....	.....	293
1933	0	.....	0	.....	.....	.....	.....	.....	0	0	.....	0	.....	.....	.....	0
1932	0	.....	0	.....	.....	.....	.....	.....	0	1,000	.....	465	.....	.....	.....	579
1931	0	.....	0	.....	.....	.....	.....	.....	0	1,000	.....	515	.....	.....	.....	515
1930	0	.....	0	.....	.....	.....	.....	.....	0	4,000	.....	702	.....	.....	.....	702
1929	0	.....	0	.....	.....	.....	.....	.....	0	1,000	90	89	.....	.....	.....	89
1928	0	.....	0	.....	.....	.....	.....	.....	0	1,000	.....	630	.....	.....	.....	452
1927	0	.....	0	.....	.....	.....	.....	.....	0	1,526	.....	1,022	.....	.....	.....	847
1926	0	.....	0	.....	.....	.....	.....	.....	0	1,500	.....	1,238	.....	.....	.....	758
1925	0	.....	0	.....	.....	.....	.....	.....	0	1,099	.....	873	126	.....	.....	626
1924	0	.....	0	.....	.....	.....	.....	.....	0	1,500	.....	1,410	13	.....	.....	?
1923	0	.....	0	.....	.....	.....	.....	.....	0	501	.....	494	.....	.....	.....	?
1922	51	Escaped	0	.....	.....	.....	.....	.....	0	500	500	451	.....	.....	.....	451
1921	208	190	.....	91.3	.....	.....	.....	.....	572	1,000	1,572	1,334	.....	84.9	.....	?
1920	316	280	.....	88.6	.....	.....	.....	.....	912	600	1,512	1,387	.....	91.7	.....	?
1919	.....	227	.....	.....	84.5	263	.....	.....	798	1,000	1,798	1,550	.....	86.2	.....	?
1918	870	700	.....	80.5	.....	.....	.....	.....	2,613	.....	.....	2,390	.....	91.5	.....	1,078
1917	835	671	.....	80.4	.....	.....	.....	.....	.....	.....	.....	2,577	.....	.....	.....	750
1916	1,031	887	491	86.0	.....	.....	7,615	.....	3,739	.....	.....	3,029	.....	81.0	.....	2,978
1915	725	.....	.....	.....	.....	.....	.....	.....	1,953	.....	.....	1,710	.....	87.5	.....	1,710
1914	693	581	289	83.8	.....	.....	6,763	.....	1,954	.....	.....	1,804	.....	92.3	.....	1,804
1913	.....	.....	.....	.....	.....	823	.....	.....	.....	.....	.....	2,573	.....	.....	.....	2,573
1912	1,133	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3,492	17	.....	.....	3,499

1914	930	864	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2,573	.....	.....	.....	2,573
1913	.....	.....	.....	.....	.....	823	.....	.....	.....	.....	.....	.....	3,492	17	.....	.....	3,499
1912	1,133	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1911	.....	.....	.....	.....	.....	481	.....	.....	1,904	.....	1,904	1,841	4	96.9	.....	1,846
1910	.....	.....	.....	.....	.....	829	.....	.....	.....	.....	.....	2,854	23	.....	.....	2,877
1909	.....	.....	.....	.....	.....	314	.....	.....	.....	.....	.....	1,217	23	.....	.....	1,240
1908	.....	.....	.....	.....	.....	256	.....	.....	.....	.....	.....	648	238	.....	.....	886
1907	.....	.....	.....	.....	.....	504	.....	.....	.....	.....	.....	2,080	24	.....	.....	2,104
1906	.....	.....	.....	.....	.....	583	.....	.....	.....	.....	.....	2,157	30	.....	.....	2,187
1905	.....	.....	.....	.....	.....	564	.....	.....	.....	.....	.....	1,898	40	.....	.....	1,937
1904	.....	.....	.....	.....	.....	219	.....	.....	984	.....	.....	727	79	.....	.....	807
1903	.....	.....	.....	.....	.....	737	.....	.....	3,462	.....	.....	2,567	289	.....	.....	2,856
1902	614	589	.....	95.9	.....	.....	.....	.....	.....	.....	.....	1,582	369	.....	.....	1,951
1901	238	.....	.....	.....	.....	.....	.....	.....	832	.....	517	49	303	.....	65.6	352
1900	212	150	84	70.8	.....	.....	7,919	614	665	.....	460	10	282	.....	62.8	292
1899	408	.....	.....	.....	.....	.....	.....	.....	1,882	.....	.....	908	183	.....	.....	1,090
1898	472	365	.....	77.3	.....	.....	.....	.....	2,148	.....	1,492	449	543	.....	55.0	988
1897	.....	.....	350	.....	76.6	752	10,019	777	3,507	.....	.....	1,975	392	.....	.....	2,230
1896	710	539	353	75.9	.....	.....	9,043	723	3,192	.....	2,702	1,769	220	.....	30.8	205
1895	390	179	111	45.9	.....	.....	9,255	625	1,027	.....	.....	19	?	.....	.....	?
1894	174	71	38	40.8	.....	.....	10,930	.....	415	.....	.....	0	152	.....	.....	152
1893	242	146	95	60.3	.....	.....	8,484	.....	806	.....	.....	231	186	.....	.....	186
1892	222	170	108	76.6	.....	.....	10,264	.....	1,109	.....	.....	?	?	.....	.....	?
1891	267	225	137	84.3	.....	.....	8,783	.....	1,203	.....	.....	0	1	.....	.....	1
1890	133	77	52	57.9	.....	.....	10,642	.....	553	.....	.....	0	254	.....	.....	0
1889	410	292	186	71.2	.....	.....	10,237	.....	1,904	.....	247	0	114	.....	46.1	104
1888	612	435	255	71.1	.....	.....	8,836	.....	2,253	.....	.....	217	91	.....	.....	110
1887	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	36	0	14	.....	38.8	14
1886	205	147	101	71.7	.....	.....	11,473	.....	1,159	.....	.....	612	.....	.....	.....	612
1885	691	501	.....	72.5	.....	.....	.....	.....	2,500	.....	.....	.....	.....	.....	.....	?
1884	568	432	240	76.1	.....	.....	8,063	806	1,935	.....	.....	.....	.....	.....	.....	387
1883	431	267	211	62.0	.....	.....	12,014	667	2,535	.....	.....	.....	.....	.....	.....	688
1882	586	440	250	75.1	.....	.....	8,360	643	2,090	.....	.....	.....	.....	.....	.....	195
1881	514	358	232	69.6	.....	.....	11,610	699	2,693	.....	.....	.....	.....	.....	.....	297
1880	522	413	227	79.1	.....	.....	8,505	654	1,931	.....	.....	.....	.....	.....	.....	147
1879	264	59	19	.....	.....	.....	11,142	906	212	.....	.....	.....	.....	.....	.....	0
1878	0	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0
1877	0	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0
1876	0	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0
1875	0	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0
1874	601	521	343	86.6	.....	.....	8,911	637	3,057	.....	.....	.....	.....	.....	.....	355
1873	650	422	279	64.9	.....	.....	8,322	626	2,322	.....	.....	.....	.....	.....	.....	210
1872	692	355	225	51.3	.....	.....	.....	.....	1,560	.....	.....	.....	.....	.....	.....	67

[1]1927 to 1936 plantings from Dow (unpublished manuscript).

In order to test the relative effect of each method on the number of adult salmon produced the number of eggs estimated to have been spawned naturally each year was correlated with the rod catch five years later, with a resulting coefficient of correlation of $+0.67 \pm 0.092$. The total estimate of both naturally-spawned and hatchery-incubated eggs was next correlated with the rod catch five years later, yielding a correlation coefficient of $+0.69 \pm 0.088$. There is no significant difference between the two coefficients, so that the addition to the correlation of the artificially handled eggs did not significantly improve the relationship.

An approach to the problem that does not entail an attempt to assess the actual difference in the extent of natural and artificial propagation, and therefore may be less subject to error may be had by considering the relationship of the three variables: A, the rod catch each year as a criterion of the size of the run; B, the rod catch 5 years earlier used to indicate the probable extent of the natural spawning that went toward producing the run; and C, the number of young salmon planted from eggs taken 5 years before used as a measure of the contribution of artificial propagation toward producing the run.

The correlations between these three variables and the partial correlations obtained when one independent variable is held constant are as follows:

Correlation between factors:

First factor	Second factor	r	r^2
A	B	+ 0.6585	0.434
A	C	+ 0.3435	0.118
B	C	+ 0.3637	0.132
Partial correlations		———	———
Factors correlated	Factor held constant	———	———
AB	C	+ 0.6100	0.372
AC	B	+ 0.1483	0.022

The simple correlations on the first three lines of the above table each include variation due to the third variable. For instance, the correlation between A, the catch, and C, the fry plants 5 years before, would indicate that 11.8 per cent (r^2) of the variation in the runs was due to artificial propagation, but the positive correlation between fry plants and the catch five years before, B and C, show this to be

an artifact. When the influence of B is held constant the influence of fry plants on the variations in the runs is seen to be not 11.8 but 2.2 per cent.

If the variation in the catch due to fry plants, 2.2 per cent, is divided by the variation due to natural spawning, 37.2 per cent, the result shows artificial propagation to have contributed 5.9 per cent as much as natural propagation toward maintaining the run.

During the whole period of years from 1893 to 1939, artificial propagation thus appears to have contributed about 5 to 6 per cent as much as natural propagation toward maintaining the run. If the estimate of the amount of eggs spawned naturally is correct, this means that artificial propagation with 10.9 per cent of the eggs (disregarding losses of adults in retaining ponds and stripping losses) contributed only 5 to 6 per cent of the run.

As the estimate of hatchery efficiency showed a tendency toward improvement the question is bound to arise as to the influence exerted by artificial propagation during the recent years. In studying these recent years it is obvious that the catch has been declining rapidly. For this reason the per cent each year's rod catch formed of the trend (smoothed twice by 5's) has been used instead of the actual catch as otherwise the rapid change in abundance would obscure the effect of reproduction. For the years 1930 to 1938, inclusive, each year's rod catch (expressed as a percentage of the trend) was correlated both with the rod catch 5 years before (again expressed as a percentage) and with the number of fry planted 5 years before. The number of fry planted also showed a positive correlation with the catch the year the eggs were obtained.

The partial correlation of rod catch with the rod catch five years before with the fry planting held constant is +0.81. The partial correlation of rod catch with fry plantings from eggs spawned five years before, with the rod catch five years before held constant, is +0.26.

The coefficients of determination indicate that in recent years 65 per cent of the variation in rod catches was associated with the rod catches five years before (presumably indicating the amount of natural reproduction) and 6.9 per cent was due to artificial propagation. The 10.6 per cent obtained by dividing 6.9 per cent by 65.0 per cent indicates that artificial propagation had 10.6 per cent as much effect as natural propagation in maintaining the runs during this period.

The estimate made previously of the actual amount of natural and artificial propagation in terms of quantities of eggs shows that from 1925 to 1933 (the years producing the runs of 1930 to 1938) artificial propagation used 4.9 per cent as many eggs as the natural spawning. This would indicate that artificial propagation, although having less effect than natural throughout the whole period considered, showed about twice as much effect in recent years as in earlier years.

Whether the increased effectiveness of artificial propagation in recent years is due to an increase in efficiency of artificial methods or a

decrease in the efficiency of natural spawning is a moot question. Certainly the poor fishway over the Bangor Dam from 1923 to 1938 combined with the poor fishways (recently improved) on some of the upriver dams, would indicate some loss in the natural run. On the other hand the smaller numbers of eggs handled in recent years by the hatchery have undoubtedly made it possible to exercise more care in the distribution of the young salmon.

Conclusions

1. Artificial propagation of salmon on the Penobscot River was not significantly more efficient than natural spawning over most of the period from 1872 to 1939.
2. Artificial propagation handled such a small proportion of the eggs during most of the period of years considered that it could not have been expected to exert any major influence on the size of the runs.
3. In spite of artificial propagation there has been a tremendous decline in the abundance of salmon in the Penobscot River.

Discussion

The part that can and should be played by artificial propagation in the restoration and maintenance of the Atlantic salmon runs can be clearly understood only by viewing the whole problem.

Before the salmon runs were exploited, the land tilled, or the streams disturbed, large runs of salmon maintained themselves by natural propagation. Because a species must always produce a surplus of young in order to survive periods of adversity, and because there is usually a moderate increase in the rate of survival as the number of spawners in an area is reduced, man can safely remove a portion of each year's run. The size of the surplus that can be removed year after year without impairing the availability of future surpluses of equal magnitude, is not necessarily correlated with the absolute size of the population.

The available surplus is at a maximum when there is the greatest difference between the number of adults returning to the river and the number of spawning adults that produced them. If the population is too greatly reduced the number of young will be insufficient to provide a large surplus within the possible range of survival. On the other hand, if an attempt is made to maintain too large a population the decreased rate of survival resulting either from over abundant young or crowding on the spawning beds will result in a smaller surplus.

On the Penobscot River the situation has been complicated by many factors. If the stream had remained in its natural state, then the populations might have been able better to withstand the heavy drain of the fishery. However, the combined effects of heavy fishing, obstructions to migration and possibly changes in the stream environment accompanying soil erosion, deforestation and the use of stream

beds for log drives, soon reduced the population to a mere remnant.

That large runs of Atlantic salmon can be maintained by natural propagation if natural conditions are suitable and the runs are not overfished is demonstrated on many Canadian rivers. The Dennys River in eastern Maine has demonstrated that removing obstructions to suitable spawning grounds and lessening the fishing pressure (accomplished in this case by buying the weir sites) may enable a very small run to recuperate.

Judging from past statistics and from the large number of unspoiled spawning tributaries available it is obvious that the Penobscot should be easily capable of maintaining a run of several thousand salmon. Obviously, such a run would have to depend for its continuance on natural spawning, since only enormously expanded hatchery facilities could care for the number of eggs and young involved. There is some possibility, however, that a program for controlling the numbers of competing and predator species, such as bass, suckers and pickerel, in order to raise the growth and survival rates of the young salmon in the tributaries, might be helpful in increasing the size of the available surplus that could be harvested annually.

One must recognize clearly both the capabilities and the limitations of artificial propagation in order to determine how it fits into the salmon restoration program. It is strictly limited in the quantity of young that can be reared to a size sufficiently large to gain a significant increase in survival over natural propagation. This means that the idea, so often expressed, that the cure for overfishing is hatcheries (instead of less fishing) is fallacious. It is not practical to maintain a large run wholly by artificial propagation.

Hatcheries can be of value by providing young salmon to restock streams or tributaries for the reestablishment of former runs, and by increasing the survival of young during the early period of restoration when the hatcheries can handle a significant proportion of the total eggs in the spawning run.

Appendix

Correlation of commercial and rod catches

In the 24 years from 1893 to 1923 in which data for both are available, the rod catches average 2.2 per cent of the commercial catch. The annual deviations in the commercial catch and the deviations in the per cent the rod catch formed of the commercial catch were correlated, resulting in a significant correlation of +.5871, showing that the variations in the two sets of data are fairly closely associated rather than due entirely to random variation.

Before using the rod catches for purposes of comparing different years it was first necessary to correct the rod catches after 1923, as explained in the text, to place the catches before and after this date on the same plane. The best criterion of the difference in level of the

two periods is contained in the comparison between the commercial and rod catches. For this purpose the regression of rod catch on commercial catch was calculated for the earlier period.

In years when the commercial catch is high the rod catch tends to form a lower percentage of the commercial catch and vice versa. In order to correct the 1924-38 rod catches this tendency was determined by calculating the regression of rod catch on commercial catch. The regression $y = a + bx$ of the deviations in rod catch percentage, y, on the commercial catch deviations, $x.b = -0.0003639.\overline{y} = 2.2.\overline{x}, = 4400$.

From 1924 to 1938, inclusive, the actual rod catches for the nine years in which both rod and commercial catches are available, average 174 ± 37 per cent higher than those calculated from the commercial catches by this regression obtained for the 1895 to 1923 period. Therefore the rod catches for the 1924 to 1938 period have been adjusted by the factor 0.575, i.e. 100 divided by 174 to put them on the same basis as the other years. (See column 5, Table 2.)

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A TECHNIQUE FOR CONTROLLING INFECTIOUS DISEASE IN HATCHERY FISH

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ABSTRACT

A need for a simple and effective direct treatment for fish in ponds and troughs has long been apparent among fish-culturists. A direct treatment not only would obviate all need for handling fish already weakened by disease but it could be used as a routine prophylaxis to eradicate diseases in their earliest stages long before their presence is suspected.

The technique described in this article has been tested, both in the laboratory and at the producing hatchery, over a period of years, and has been found effective in eliminating infections by the common exoparasites and bacterial gill disease.

In brief, the method consists in determining the quantity of water present in a pond or trough, stopping the inflowing water, and adding sufficient disinfectant-concentration. After one hour, the flow of water is resumed. If adequate precautions are exercised, the hatcheryman can effectively control the common diseases of hatchery fish with no risk of injury to his stock.

INTRODUCTION

A direct method for controlling diseases among hatchery fish has long been sought as an alternative to the earlier technique of hand dipping. A simple, practical, and effective method of direct pond treatment not only obviates all need for handling fish weakened by disease, but it would materially reduce the time and effort required by hatcherymen in keeping diseases under control. Furthermore, a direct pond treatment could be used for routine prophylaxis to eradicate diseases during their incipient stages—long before their presence becomes apparent.

Several methods for applying direct pond treatments in cold-water fish culture have been proposed. Kingsbury and Embody (1932) developed a technique for applying disinfectants directly to the inflowing water of a pond. Later, Fish (1939) advocated a method involving the recirculation of a disinfecting solution through a fish pond. For various reasons, neither of these methods proved to be an effective answer to the problem of controlling hatchery diseases and neither became widely adopted.

The method described herein has been extensively tested, both in the laboratory and at the producing hatchery, over a period of several years. Once familiarity with the details of application have been mastered, the reduction in effort required to treat fish is amazing. For

example, two men have treated 20 large ponds, containing several million fish, in one day with no significant increase in mortality of the fish, whereas a crew of eight men required a full day to treat a single similar pond by hand dipping the fish with a subsequent loss approximating 50 per cent of the stock.

Weekly prolonged treatments with Roccal have been adopted as part of the routine fish-cultural operations at the Leavenworth (Washington) hatchery since 1943, with the result that no mortality attributable to bacterial gill disease has been experienced among the fingerling stock receiving the treatments since that time.

Recommended Technique of Application

1. basic calculations

If the weight of water contained in a pond or trough is known, any desired concentration of disinfectant can be obtained and held for a desired period of time merely by shutting off the inflowing water and adding the required quantity of disinfectant. This, in essence, constitutes the method recommended for applying prolonged treatments.

Two disadvantages immediately become apparent. A uniform distribution of the disinfectant would be required to avoid the formation of localized areas of hyperconcentration, or "hot spots" that might prove toxic to the fish. Furthermore, cold-water fishes would quickly deplete the store of essential oxygen contained in the water and suffocate. By exercising suitable precautions, however, both of these difficulties can be overcome.

Certain basic data are required before the time of treatment to assure a safe and effective application. The volume of water contained in the pond or trough at regular intervals of depth is a necessary basis for calculating the quantity of disinfectant required. As disinfectant-concentrations are expressed in terms of weight for both disinfectant and water, conversion of the pond volume to weight is required. Once determined, however, the basic data may be filed for ready reference whenever a treatment is needed. For convenience, use of the metric system is recommended. Not only are cubic centimeters and grams much smaller units than cubic inches and pounds, but they possess the convenient relationship of one cubic centimeter of water weighing one gram. Thus, by calculating the volume of water contained in a pond in terms of cubic centimeters, one also calculates the weight of that water in grams. This is not true of cubic inches and pounds.

Determination of the weight of water present at progressive depths.—The weight of water contained in a pond or trough of regular outline, may be quickly and easily calculated by standard mensuration formulae. The volume of water in terms of cubic inches contained in a rectangular pond at 1-inch center depth may be calculated by multiplying the length by the width—both measurements being taken in inches. The volume of water present at any desired depth then may be

obtained by multiplying the volume at the 1-inch depth by the number of inches of desired depth. The volumes then may be converted into cubic centimeters (and thus to weight expressed in grams) merely by multiplying the volume in cubic inches by 16.4.

In the case of irregularly shaped ponds, or ponds such as the Foster-Lucas type, calculation of the weight of water present at progressive depths by the use of formulae becomes too involved. It is simpler merely to plug the drain water-tight and then add known weights of water by any convenient method. The depths attained by known weights of water then can be marked on some permanent vertical structure in the pond, such as the tailscreen guides, for future reference. A water meter often may be borrowed for a sufficient period of time to calibrate all ponds at a hatchery. As these instruments usually are read in terms of cubic feet, the values can be converted into grams by multiplying the volume in cubic feet by 28,339.

The determination of the weight of water present at progressive intervals of depth does involve some initial effort, but once obtained, the record is of permanent application.

Usually, a table is prepared for reference when treatments are needed. The table should show the weight of water present in a pond at progressive intervals of depth and the quantity of disinfectant required to produce the concentration desired for treatment. At the present time, the only disinfectants known to be efficacious in prolonged treatments are formalin, which is used at a concentration of one gram in each 4,000 grams of water (usually written as 1:4,000), and Roccal used at a 1:50,000 concentration. The weight of disinfectant (in grams) required to produce a desired concentration is obtained by dividing the weight of water present by the disinfectant-concentration desired.

Liquid disinfectants, for the sake of convenience, may be considered as weighing one gram per cubic centimeter. If 99.2 grams of a liquid disinfectant are required, for example, it will be sufficiently accurate to measure 99 cubic centimeters in a graduated glass cylinder.

As an example of the basic calculations required, assume that a hatchery is equipped with a series of rectangular ponds having uniformly sloping bottoms. The internal length of the ponds is 30 feet and the internal width is 6 feet. At a 1-inch depth (measured at the center of the pond), the pond will contain: $(30 \times 12) \times (6 \times 12)$, or 25,920 cubic inches. Converting to grams: $25{,}920 \times 16.4$ yields 425,088 grams of water present at the 1-inch depth. For each 1-inch of depth, therefore, 106 grams of formalin will be required to produce a 1:4,000 concentration ($425{,}088 \div 4{,}000$). Likewise, 8.5 grams of Roccal will be required to produce a 1:50,000 concentration ($425{,}088 \div 50{,}000$). The hatcheryman then would prepare a reference table somewhat as follows:

Depth of pond at center (in inches)	Weight of water present (in grams)	Weight of formalin required (in grams) (1:4,000)	Weight of Roccal required (in grams) (1:50,000)
1.....	425,088	106	8.5
6.....	2,550,528	638	51.0
7.....	2,975,616	744	59.5
8.....	3,400,704	850	68.0
9.....	3,825,792	956	76.5
10.....	4,250,880	1,063	85.0
11.....	4,675,968	1,169	93.5
12.....	5,101,056	1,275	102.0

2. Calculations Required at the Time of Treatment

Treatments administered to ponds will require an adjustment of the weight of water present during the treatment to a definite relationship with the total weight of the fish being treated. This precaution lessens the risk of suffocation during treatment; it greatly facilitates thorough mixing of the disinfectant with the pond water; and it reduces the quantity of disinfectant required. In the case of troughs, adjustment of the weight of water to the weight of fish present is not necessary as, in most instances, the quantity of disinfectant saved is insignificant, thorough mixing is easily accomplished, and the weight of fish present usually permits no reduction in the quantity of water present.

Obviously, determination of the weight of fish present in a pond cannot be made long in advance of treatment. The total weight of fish confined in a pond is periodically determined, or estimated, at hatcheries practicing feeding on the basis of body weight. Except under conditions of maximum growth rates, weight records obtained within a week or two of the time of treatment are sufficiently accurate for this purpose. At hatcheries where no record of the weight of stock is maintained, the average length and the number of fish in each pond is, or should be, known. The relationship between total length and body weight may be grossly approximated by reference to figure 1. The approximate body weight multiplied by the number of fish present yields the approximate total weight of the fish in the pond.

Under conditions wherein the fish have been starved for a period of 24 hours prior to treatment, the water temperature lies between 50° and 60° F., and the water contains a normal complement of dissolved oxygen, a relationship of 75 grams of water for each gram of fish present is ample to maintain the fish safely, without additional water, for 90 minutes which represents an adequate factor of safety for a 60-minute treatment.

In instances wherein the fish cannot be starved for 24 hours prior to treatment, or the incoming water is significantly undersaturated with dissolved oxygen, or the water temperature is in excess of 60° F., or the fish are suffering from a gill disorder or anemia, the relationship between the weight of the fish present and the weight of water present should be reduced, possibly to 1:100 or even less, according to circumstances. Conversely, if the water temperature is below 50° F., a relationship between the weight of the fish present and the weight of

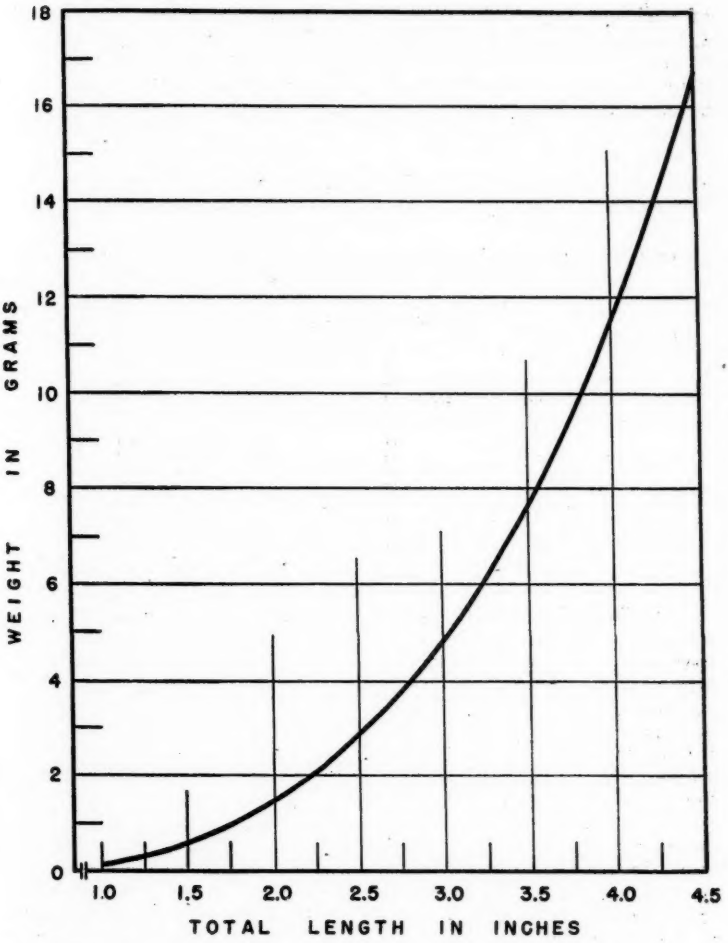

FIGURE 1.—Approximate length-weight ratio for hatchery trout and salmon.

water of 1:50 can be employed with safety.

The effect of two dominant variables, namely the recency of feeding and water temperature upon the rate of oxygen consumption, is

of sufficient importance to warrant further consideration. Table 1 summarizes data obtained from laboratory experiments in which each of these factors was considered as a single variable. The marked increase in oxygen required by the fish as a result of the higher water temperature, and the decrease in oxygen-demand as time elapses following feeding emphasize the need for revision of the relationship between the weight of the fish and the weight of water present during treatment according to the importance of the variables at the time of treatment.

TABLE 1.—*The effect of water temperature and recency of feeding upon the oxygen consumption of 2-inch chinook-salmon fingerlings*

Temperature (°C.)	Elapsed time since feeding (in hours)	Approximate oxygen consumption (expressed as milligrams of oxygen consumed per hour)
50	1	23.0
	24	19.8
	48	15.0
	72	12.6
	96	12.6
55	1	27.8
	24	24.6
	48	20.6
	72	17.7
	96	17.1
60	1	34.6
	24	31.0
	48	22.9
	72	17.5
	96	17.6

The effect of two other variables, not so easily measured, nevertheless should be considered. Any physiological handicap to the normal respiratory processes of the fish obviously would directly affect the safe duration of treatment. Gill disorders and anemia are two very important and common handicaps to normal respiration. Anemic fish will lose equilibrium and exhibit every indication of suffocation when the water still contains six parts per million of dissolved oxygen whereas normal fish will tolerate a reduction to less than three parts per million with no apparent ill effect. Advanced anemia may be detected easily by the pink to white coloration of the gill filaments in contrast to the cherry-red gill filaments of the healthy fish. Gill disease offers a similar handicap to the respiration of the fish although its presence can be detected only with a microscope. If the presence of either anemia or advanced gill disease is suspected, it is advisable to use a low ratio between the weight of the fish and the weight of water present.

As an example of the calculations required at the time of treatment, assume that one of the ponds previously quoted carried a normal operating water depth of 14 inches. At the time a 1:50,000 Roccal treatment was needed, the pond contained 94 pounds of fish, the water temperature was 57° F., the fish had not been starved, and the gill

disease present had not advanced to the stage where respiration was materially handicapped. The pounds of fish present should be converted to grams, merely by multiplying by 453. The answer of 42,582 is obtained. All factors considered, the hatcheryman probably would choose a 1:75 relationship between the weight of the fish and the weight of the water that should be present in the pond during treatment. To determine the weight of water required to form the 1:75 ratio, the weight of the fish present (in grams) would be multiplied by 75, yielding an answer of 3,193,650. By consulting the permanent pond calibrations, it is found that the nearest point over the desired value is the 8-inch level at which the pond contains 3,400,704 grams of water. The table also shows that 68.0 grams of Roccal will be required to form a 1:50,000 concentration at the 8-inch depth. The excess water present in the pond over the 3,193,650 cubic centimeters actually needed tends to compensate for the fact that the fish had not been starved. At the time of treatment, therefore, the hatcheryman would drain the pond from the normal operating level of 14 inches to the treatment level of eight inches before adding the disinfectant.

3. APPLYING THE TREATMENT

After the quantity of water to be present during treatment has been determined, the next steps are to shut off the inflowing water and to add the proper quantity of disinfectant to form the desired concentration in the quantity of water present.

It is essential that the disinfectant be so applied as to form a homogeneous concentration throughout the pond or trough in the shortest possible time, thus avoiding the formation of "hot spots" that would be toxic to the fish.

The most effective means of applying the disinfectant depends upon the particular type of rearing equipment being treated. In all cases, however, the disinfectant should be diluted with at least 100 times its weight of water—the more dilute the disinfectant at the time of application, the less consequential are the unavoidable irregularities in distribution. In no instance should the time required to distribute the diluted disinfectant exceed 15 minutes.

Trough treatments best can be applied with an ordinary garden sprinkling can. It is advisable to fill the can with water taken from the trough *after* the inflowing water is stopped. The full strength disinfectant may be rapidly mixed with the water in the sprinkling can and the mixture then spread evenly over the water surface as shown in Figure 2. Following the addition of the diluted disinfectant, it is advisable to facilitate thorough mixing by two or three trips over the length of the trough with a wide flat paddle.

Small ponds of the raceway type can be treated in exactly the same manner as troughs. Large ponds, however, require too great a volume of 1:100 diluted disinfectant to be added within the required period

of 15 minutes by means of sprinkling cans. In this event, it is necessary to resort to some type of power sprayer that is capable of handling large quantities of liquids.

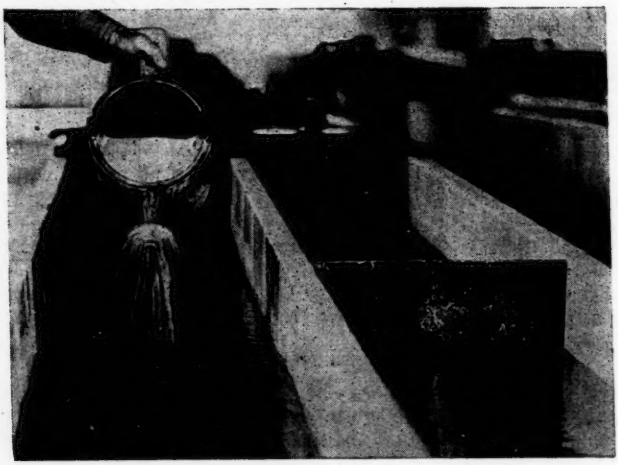

FIGURE 2.—Applying pre-diluted disinfectant to troughs. Thorough mixing of the disinfectant and trough water should accompany, or immediately follow, addition of the disinfectant.

A portable spraying outfit that has proven satisfactory is illustrated in Figure 3. It consists of a motor-driven, 1-inch, herring-bone gear pump with an injector mounted on the intake arm which introduces the prediluted disinfectant into the circulating water. A pump of this type will deliver about 12 gallons per minute against a backpressure of 20 pounds when turning to 900 r.p.m. A one-third horsepower motor will produce ample power for the pump, yet requires sufficiently little current to permit its attachment to the usual electrical circuit. The injector on the inlet arm of the pump consists of a "T" bearing a one-eighth-inch needle valve inserted in the hose line from the disinfectant reservoir. The rate at which the prediluted disinfectant is added to the pond water through the pump may be controlled accurately by properly setting the needle valve. Prior to its initial use, the apparatus should be calibrated to determine how much of the disinfectant is removed from the reservoir at different settings of the needle valve. In use, the intake hose is coupled to the intake pipe and the free end dropped behind the tail screen of the pond. The required quantity of prediluted disinfectant is added to the bottle and the needle valve set to empty the bottle in approximately ten minutes.

An outlet hose, connected to the opposite side of the pump, is used to spray the greatly diluted disinfectant over the pond surface as illustrated in Figure 4. The spray unit illustrated in Figures 3 and 4 has a bifurcated outlet arm, thus permitting the use of two hoses in the distribution of the disinfectant. This type of spray unit also may be used to provide supplemental aeration during treatments in exceptionally crowded ponds.

Recently, R. E. Burrows (unpublished data) has developed a time-saving modification of the foregoing technique for applying prolonged treatments to the circulating type of rearing pond. A disinfectant ice is formed by freezing a solution of 1,000 cubic centimeters of Roccal and 44,452 cubic centimeters of water (1 quart of Roccal and 47 quarts of water) hence each pound of ice contains ten grams of disinfectant. The ice is broken into particles not exceeding three inches in diameter at the time of treatment. The pond water is drawn slightly below the treatment level and the broken ice shovelled into the pond in a manner assuring an even distribution over the pond surface. The inflowing water is stopped when the final treatment level is reached. The modification proposed by Burrows involves a distinct saving of time as the ice can be uniformly distributed over a pond in about two minutes in comparsion with eight to ten minutes with the pump.

The actions of the fish should be carefully watched during treatments. Although the recommended relationships between fish weight and water weight have been established with a considerable margin of safety, they cannot be regarded as infallible under all conditions. Fish gulping at the surface indicate the gradual approach of the suffocation threshold although it is not ordinarily an index of immediate danger. The first evidence of gulping usually appears when the dissolved oxygen has been reduced about half way from the initial concentration to the suffocation threshold. Periodic dissolved-oxygen determinations made during the treatment are desirable, when they can be obtained, particularly until some experience has been acquired with the water concerned.

At the conclusion of the desired period of exposure—which is calculated from the time at which addition of the disinfectant is completed—the water flow to the pond should be resumed immediately and even increased above the normal operating volume to the maximum that will not sweep the weaker fish against the tail screen. To facilitate the complete and rapid removal of the disinfectant, the pond drain should be opened sufficiently to merely maintain the reduced level. After the disinfecting solution has been replaced by fresh water, the normal pond level and volume of inflow should be restored.

It is recommended that the inexperienced hatcherymen first apply treatments to fish in troughs. Pond treatments should not be attempted until complete familiarity with, and understanding of, the details of application have been gained from repeated and successful

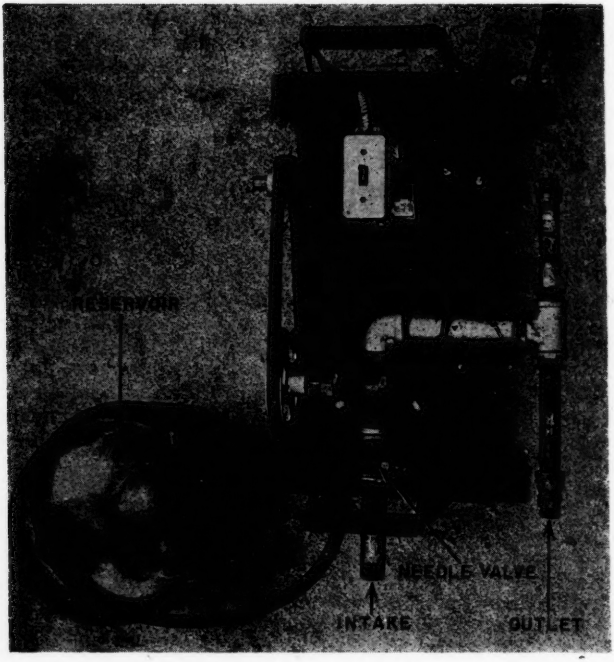

FIGURE 3.—A portable motor-driven spray outfit developed for the application of prolonged treatments to large ponds.

FIGURE 4.—Applying disinfectant to large ponds by means of the spray outfit illustrated in Figure 3. Extreme care must be exercised to distribute the diluted disinfectant as evenly as possible over the pond surface.

trough treatments. The mortality subsequent to treatment should be used as an index of the correctness of the technique being employed. Properly applied in the manner described, prolonged treatments will incur no significant increase in the daily mortality rate even among fish somewhat weakened by disease.

Recommended Concentrations of Disinfectants and the Period of Exposure

1. parasitic diseases

A single 1-hour exposure to a 1:4,000 concentration of formalin[1] will remove the common external parasites of hatchery fish. As shown in Table 2, formalin treatments are more effective against the common parasites than are the usual hand dips in copper sulphate, acetic acid, or salt.

Formalin treatment may be used effectively, either as a routine prophylactic measure to prevent epidemics, or as a therapeutic after the infections become evident. Formalin treatments have been demonstrated to eradicate infections by *Costia, Chilodon, Ichthyophthirius, Gyrodactulus* and certain of the stalked protozoans that occasionally attach themselves to fish.

As a phophylactic measure, the routine application of a 1:5,000 concentration of formalin for 1 hour at 2-week intervals is recommended during periods when outbreaks of these parasites are anticipated. Routine prophylaxis with formalin, however, is advisable only during periods when considerable trouble from the external parasites ordinarily is encountered.

As a therapeutic measure, given after evidence of parasitism has been established, a single 1-hour exposure to a 1:4,000 concentration of formalin will effectively eradicate all of the external parasites except *Ichthyophthirius.* To combat this parasite, daily applications of 1:5,000 formalin for one hour are required over a period of seven to fourteen days. Only those stages in the life history of this parasite that are not on the fish can be reached by formalin treatments, hence daily applications are necessary to kill these stages before they can reinfect the fish.

As an alternative therapeutic measure in instances wherein the usual one-hour exposure is not possible because of exceptionally crowded troughs or abnormally low dissolved oxygen concentrations, a 20-minute exposure to 1:4,000 formalin administered on three consecutive days will prove equally effective as a single one-hour treatment.

[1]Formalin is used herein to designate a 40 per cent aqueous solution of formaldehyde gas to which has been added a small quantity of methyl (wood) alcohol to prevent polymerization. In trade, this solution is commonly referred to as "formaldehyde" although strictly speaking, formaldehyde exists only as a gas at ordinary temperature. The U.S.P. grade of formalin should be used for treatment of fish.

Formalin 1:6,000 has been recommended in one-hour exposures as an effective measure for eradicating parasitic copepods. A 30-minute exposure to a 1:200 concentration of formalin has been recommended by Watenabe (1940) to combat fungus growing on developing eggs and for the so-called "soft-egg". Confirmation of these two suggested uses of formalin treatments is, as yet, lacking.

Certain of the stalked *Ciliata* occasionally encountered attached to hatchery fish appear quite refractory to formalin treatments. Although all available evidence points to the fact that these organisms are quite harmless, they may be removed, if desired, by a single, one-hour exposure to a 1:10,000 concentration of glacial acetic acid administered in exactly the same manner as formalin. The effect of the

TABLE 2.—*The relative efficacy of various treatments in removing certain external parasites from trout*

[After: Fish, 1940; and Fish and Burrows, 1940]

Parasite	Disinfectant-concentration	Period of of exposure (in minutes)	Number of parasites on 5 fish	
			Immediately before treatment	24 hours after treatment
Trichodina (Cyclochaeta)	Copper sulphate 1:2,000	2[1]	5,386	2,001
	Acetic acid 1:500	2[1]	7,334	5
	Salt 5 per cent	10[2]	3,680	34
	Formalin 1:2,000	30	4,336	19
	Formalin 1:2,000	60	4,214	0
	Formalin 1:4,000	60	3,633	0
	Formalin 1:6,000	60	3,655	19
	Formalin 1:6,000	120	1,590	0
	Formalin 1:10,000	120	4,470	30
Gyrodactylus	Acetic acid 1:500	2[1]	.....	125
	Formalin :1,4000	60	205	0
	Formalin 1:5,000	60	345	17
	Formalin 1:6,000	60	335	10

[1]Hand Dip. [2]Salted in trough.

acetic acid upon these organisms appears to be through the action of the hydrogen ions rather than through any specific toxicity of the acetate ion. Presumably, a similar pH produced by other acids would work equally well. Caution is definitely recommended in the use of acetic acid for this purpose as the margin of safety between an effective concentration and one lethal to the fish is very narrow, much narrower than that of formalin.

2. BACTERIAL DISEASES

Formalin has no effect upon the bacterial diseases. For the control of bacterial gill disease, the application of a 1:50,000 concentration of Roccal[2] for one hour is particularly effective.

[2]"Roccal" is the trade name of a 10-per cent solution of the high molecular group of alkyl-dimethyl-benzyl-ammonium chlorides. It is manufactured by the Winthrop Chemical Company, 17 Varick Street, New York 13, and by various licenses. When ordering Roccal, the fact that it is to be used for fish-cultural purposes should be emphasized and shipments showing any trace of a brown coloration or an unpleasant odor should be rejected. Although Roccal is considerably more expensive than formalin, the greater dilution used reduces the cost per treatment below that of formalin.

Roccal treatments demand more care than formalin treatments for the margin of safety between an effective concentration and one toxic to the fish is very narrow. When used as recommended, however, Roccal treatments are safe and appear to actually stimulate the fish in much the same manner as do saltings.

As a curative measure, applied when bacterial gill disease is known to be present, one-hour Roccal treatments at a 1:50,000 concentration are recommended on two or three consecutive days.

As a prophylactic measure, a one-hour Roccal treatment at a 1:50,000 concentration at weekly intervals is efficacious. Controlled experiments have demonstrated that, at least under certain conditions, weekly prophylactic treatments with 1:50,000 Roccal applied as soon as the fish are free-swimming will eliminate all danger of epidemics of bacterial gill disease. The benefits derived from routine weekly Roccal treatments at hatcheries where bacterial gill disease frequently appears are well worth the low cost and slight additional effort required for their application. Weekly prophylactic treatments with Roccal appear to eliminate infections by most of the external parasites as well. Single treatments, however, appear less effective than formalin as a therapeutic measure. The potential value of Roccal, and other compounds of this nature, in the control of fish diseases have not been fully explored.

Conclusion

A technique for the direct application of certain disinfectants to hatchery ponds and troughs is described. The cost of, and the effort involved in, controlling common diseases at fish hatcheries may be greatly reduced by prolonged treatments in comparison with the usual method of hand dipping. The particular advantage of prolonged treatments applied as described lies in their value as routine prophylactics to eliminate infections by the commoner parasitic and bacterial diseases of hatchery fishes in the early stages before their presence can be detected.

Promptly and properly applied, prolonged treatments will incur no significant mortality, even among fishes somewhat weakened by disease. In fact, the mortality subsequent to treatment should be used as an index of the procedure employed—any significant increase in mortality being indicative of an incorrect application or of failure to compensate adequately for pertinent variables affecting this type of treatment.

Approximate Conversions

TO CONVERT:

1. Cubic inches to cubic centimeters, multiply by 16.4.
2. Cubic feet to cubic inches, multiply by 28,339.
3. Gallons to cubic centimeters, multiply by 3,785.
4. Pounds to grams, multiply by 453.
5. Ounces (avoirdupois) to grams, multiply by 28.3.

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GEOCHEMICAL INTERPRETATION OF WATER ANALYSES FROM TENNESSEE STREAMS

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ABSTRACT

The total alkalinity of unpolluted waters in Tennessee streams can be generally related to the nature of the geological formations comprising the stream beds and soil provinces. Data accumulated from 371 localities in streams which are isolated in distinct and separate geological formations show that sixteen geochemical provinces may be recognized as individually effective in determining the character of fishable streams.

INTRODUCTION

In the course of routine biological survey work which involves chemical analyses of the waters of streams at different altitudes and in varying geological formations, it is often apparent that alterations in certain chemical constituents which are estimated in the field laboratory may be attributed to types of soils and the nature of the stratigraphy. That this is true has already been pointed out by authors of geological papers such as that of Palmer (1911) in which geochemical interpretation of water analyses shows influence of sedimentary and limestone formations in regulation of the possible buffering action and pH of natural waters occurring as streams. Powers (1930, 1939, 1941) has indicated in several instances the extremely low total alkalinity and available buffer in "mountain water" from East Tennessee. The mountain streams of the Great Smokies which Powers has examined and which have been studied in connection with the present survey, generally flow through Cambrian and Pre-Cambrian strata (Unicoi formation) of partly crystalline rocks containing sandstones, shales, slates and quarzites which contribute little or no buffering action through the formation of acid carbonate (HCO_3) by contact with available limestone. In contrast, Norris Lake water, as reported by Powers (1941), of 70-90 parts per million total alkalinity, is drained from areas of the Upper Cambrian, the Knox Dolomite, and the Ordovician bearing abundant limestone. Waters which drain into Norris Lake therefore have considerable buffering action or "alkali reserve" because they have flowed through geological formations which are contributing some soluble carbonate. This soluble buffer is actually made available as acid carbonate (bicarbonate) through reaction with free carbon dioxide normally present. The quantity of bicarbonate in the streams then rises according to the nature of the bed-rock, and to a greater or less degree some free carbon dioxide remains at all times, excepting in areas which are extremely limey to an extent permitting a quantity of carbonate to remain in solution as CO_3-ion in its various combinations with calcium and magnesium; this again dependent on the nature of the bed-rock. This means that the characteristics of a particular geological formation may be re-

flected in determinations of total alkalinity, carbonates and bicarbonates, and pH, for any water sample.

It would appear from these analyses, and from those reported for the Eastern Highland Rim and Cumberland Plateau of Tennessee by Shoup (1940) and Shoup, Peyton and Gentry (1941), that some relationship could be found between the stratigraphy of stream beds and the expected and actual buffering action and pH of the streams; the more soluble bedrock contributing a greater alkali reserve and the less soluble sedimentary formations permitting a flow of softer waters. Additional investigations on streams throughout the state in every geological formation could be expected to show further correlation of total alkalinity with the nature of the stream bed.

Results

In the present study, in the course of routine biological survey[1] work, a total of 371 water analyses have been made from an equal number of different localities in streams tributary to the great river systems of Tennessee. These stations for water sampling are located throughout the state in its various soil provinces and are from streams localized in sixteen separate geological formations with respect to their bedrock.

A tabulation of the average total alkalinity as measured by titration with 0.025 N. H_2SO_4 with methyl orange indicator, the carbonate alkalinity detectable by titration with N/44 NaOH with phenolpthalein as indicator; all expressed in terms of parts per million (p.p.m.), is shown (Table 1) for stream waters from each geological region in the survey records. The *average* hydrogen-ion concentration, conventionally expressed as pH, is also indicated for the regions. A notable agreement between the geological description of the formations and the general chemistry of natural waters flowing over the particular rocks can be made out in each case. This was so striking, that members of the biological survey could examine a geological map and practically predict the chemical nature of the waters of a stream (known to be unpolluted) on the basis of the bedrock stratum indicated as predominant in the drainage area.

In the case of a large watershed, such as the Cumberland River, whose headwaters flow from regions of relatively insoluble rocks, the dilution effect can be demonstrated as it flows into hard-water regions, such as, for example, the Ordovician of the Nashville Basin of Middle Tennessee. Adjacent tributary streams of the Nashville Basin, would, of course, show high total alkalinities of 150 p.p.m. or greater when the main stream may have values near 65 p.p.m. due to dilution from the headwaters. This means that reflection of the nature of the geological formation is best shown in the smaller streams whose waters flow in a single stratum. Because no previous study of Tennessee waters has demonstrated this relationship, a tabulation of results of studies in the various geological provinces is prepared as Table 1.

[1]Supported by, and on behalf of the Tennessee Division of Game and Fish, Nashville.

TABLE 1.—*The geological correlation with analyses of natural waters from the surface streams of Tennessee*

Nature of the Geological Formation	Map Symbol	Average M.O. Alk. p.p.m.	Average P. Alk. p.p.m.	Average pH	Number of stations
Archaen: Crystalline rocks of granites, gneisses and schists. Insoluble. Soil of some fertility in the valleys but poor on higher slopes where most of the analyses were made.	AR	11.1	0.00	7.10	4
Pre-Cambrian: Unicoi Formation. Partly crystalline rocks of sandstones, quartzites, conglomerates, shales, slates. Sandy and rocky soils of poor agricultural value.	C_1	11.5	0.00	7.10	24
Cambrian: Chilhowie Formation of lower Cambrian. Quartzites, shales and sandstones of East Tennessee. Thin sandy soils of little value.	C_2	22.7	0.00	7.21	15
Cambrian: Conasauga - Watauga Formation of upper Cambrian. Considerable sandy shale and sandstone. Forms long parellel ridges and valleys in East Tennessee. Forms poor soil, but when some limestone is present becomes fertile.	C_3	21.0	0.00	7.15	30
Knox Dolomite: Light to dark magnesium limestones. Cherty. Lowlands valuable for general farming. Limestones in stream beds.	K	140.0	5.00	7.85	33
Ordovician: In Middle Tennessee. Limestones and calcareous shales of variable character. In East Tennessee of calcareous sandstones and shales producing fertile valleys.	O	133.5	9.00	7.89	51
Silurian: Minor. In Middle and West Tennessee. Variable limestone. Soil fertile where limestone is encountered.	S	55.0	0.00	.....	7
Chattanooga Shale: Patches were encountered in the Obey River watershed of the Eastern Highland Rim. In combination with some limestones, so the water chemistry is largely alkaline and characteristic of lowland streams.	Ch	104.0	2.00	7.76	5
Mississippian: Tullahoma - Ft-Payne Formation of some sandstones, shales, cherts, crinoidal limestones of variable character. Soil thin but occasionally fertile, depending on amount of limestone.	M_1	114.2	24.00	7.78	56
Mississippian: Chester-St. Louis-Warsaw Formation. Sandstones and shales in upper part, soluble limestones in lower part. Soils variable.	M_2	67.0	1.00	7.14	23
Pennsylvanian: Lee Formation. Conglomerate, sandstones and sandy shales with beds of coal and clay. Soils poor. Lack phosphate and lime.	P_1	9.9	0.00	6.42	59

TABLE 1.—(*Continued*)

Nature of the Geological Formation	Map Symbol	Average M.O. Alk. p.p.m.	Average P. Alk. p.p.m.	Average pH	Number of stations
Pennsylvanian: Jellico-Briceville Formation. Interbedded sandstones, sandy shales, argillaceous shales and coal beds. Soil sandy and stony to clayey.	P_2	16.2	0.00	7.00	16
Upper Cretaceous: Calcareous and micaceous sands and soils naturally poor in lime and phosphate. Soils respond to fertilizer. Some marl of marine origin.	C_4	17.9	0.00	6.80	9
Eocene: Wilcox Group and Holly Springs Formation. Sand, slay, with thin beds of sand and clay conglomerate. Somewhat fertile, but easily-eroded soils. West Tennessee.	E_3-E_4	20.5	0.00	6.64	16
Pleistocene: Loess. Yellowish to brown loam and sand. Soils of silty loams are fertile. Mississippi flood plain.	Q_1	39.0	0.00	7.00	5
Recent: Alluvium and terrace deposits. Bottom lands of alluvial deposition from the Mississippi River and smaller streams. Soils of high fertility but frequently swampy.	Qa	18.4	0.00	6.78	18

DISCUSSION

The State of Tennessee may present an unusual situation with respect to isolation of whole streams in particular bed-strata, and certainly where so encountered this condition offers an opportunity for study of water analyses in relation to the soluble and insoluble rocks unusual in accumulated biological survey data. In New Hampshire (Hoover, *et al.* 1937, 1938; Warfel, 1939) for example, nearly all studies were in geological formations which permitted but quite soft waters in either the lakes or streams, and in other areas where stream examination has been carried out over a period of years (Illinois, Wisconsin, Michigan), rather uniform series of bedrock formations are encountered over wide regions. The recent Minnesota studies of the north shore of Lake Superior show rather uniform and moderate total alkalinities with exception of three watersheds near the center of the drainage areas, but here again no variation is encountered comparable to that observed in Tennessee with its wide range of geological formations with their variable solubilities. (Smith and Moyle, 1944). In Tennessee, from east to west, nearly all ages of geological formations may make up the beds of streams, and in most instances the chemical character of a tributary stream may be determined by a single formation characteristic of this stream's bedrock. For this reason it is possible to determine the relative total alkalinity, carbonate alkalinity, and hydrogen-ion concentration generally imparted by each geological stratum in a manner but seldom found in the results of other biological surveys at hand in published form. As would be expected, 28

FIGURE 1.—Areas of Tennessee providing variation in the chemistry of natural waters. (For explanation see map symbols from Table 1.)

out of the 34 limestone-producing counties of Tennessee (where limestone is quarried in commercial quantities) lie within the range of highly-alkaline or "hard-water" streams shown in the data from the biological survey (Whitlatch, 1941).

A most interesting situation with respect to total alkalinity of natural waters influenced by geological formations is shown in the case of the Sequatchie River. Here a stream located in a narrow gap of the south Cumberland Plateau, has cut its way into the Ordovician and Knox Dolomite while the area on each side of the valley lies at the higher level of younger and more insoluble rocks belonging to the Pennsylvanian. As a result, water analyses from the Sequatchie River show more than one hundred parts per million total alkalinity, or ten times greater than the adjacent "soft" waters of the Plateau.

A map has been prepared (Figure 1) which indicates there are at least ten recognizable regions in Tennessee from east to west which represent bands in which one may expect to find acid, neutral or alkaline conditions in the natural waters. It is of course recognized that occasionally local situations may entirely alter the chemistry of the waters in small streams, principally due to pollution, liming of soils adjacent to the stream, or presence of local outcropping beds of limestone or other souble rocks. In general, the close relationships of these areas with the surface geology will be seen on comparison with the geological map of Tennessee (4th edition, revised, 1933), and should be confirmed through a complete chemical analysis of rocks typical of each formation. What one must regard as significant, is the unusual demonstration of geochemical relationships within the single state; an exhibit which may not apply in many areas where a rather uniform stratigraphy is predominant.

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A STUDY OF THE DEEP-WATER CISCO FISHERY OF LAKE ONTARIO WITH PARTICULAR REFERENCE TO THE BLOATER *LEUCICHTHYS HOYI* (GILL)

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ABSTRACT

Studies were made of the deep water cisco fishery on New York waters of Lake Ontario during the summer and fall of 1942. Experimental gill nets were set to test the 2¾ inch mesh, as provided under present New York regulations, against various other mesh sizes to determine if changes in the regulations were advisable in order to increase the production of ciscoes. Conclusions are based on a total catch of 2,393 ciscoes of which 93.23 per cent consisted of a single species, the bloater (*Leucichthys hoyi*). Characteristics of the different species of ciscoes and fishes associated with them were considered in formulating the recommendations. The catch of bloaters by the nets of each mesh size are analyzed with respect to number of fish taken, average length and weight, sex ratio and condition. Studies on the age and growth of the bloater are presented. A change to 2½ inch mesh was recommended for the deep water ciscoes provided that such nets are not fished in less than 180 feet of water.

INTRODUCTION

Over much of the deep water area of Lake Ontario where ciscoes are known to occur commercial fishing has not given satisfactory returns when 2¾-inch mesh gill nets are used, as provided under present New York regulations. Thus experiments were carried on to test the 2¾-inch gear against various other mesh sizes and to determine if changes in the regulations were advisable in order to increase cisco production. The experimental work was supplemented by observations on the commercial catches of ciscoes, and general studies of the fishery.

Four species of ciscoes (*Leucichthys*) are recognized from Lake Ontario. They are: *hoyi, kiyi, reighardi* and *artedi*. The fishermen commonly call the deep water fish (*hoyi, kiyi* and *reighardi*) ciscoes while the fish (*artedi*) which frequent the shoal water are known as herring. The details of description and identification of the Lake Ontario ciscoes are discussed by Koelz (1929) and Pritchard (1931).

MATERIALS AND METHODS

This study of the deep water cisco fishery on New York waters of Lake Ontario was undertaken during the summer and fall of 1942. The experimental gear consisted of gill nets of the following mesh sizes, stretched measure according to the standard 1-pound weight: 2⅜, 2½, 2⅝, 2¾ and 2⅞ inches. The nets were remeasured with the

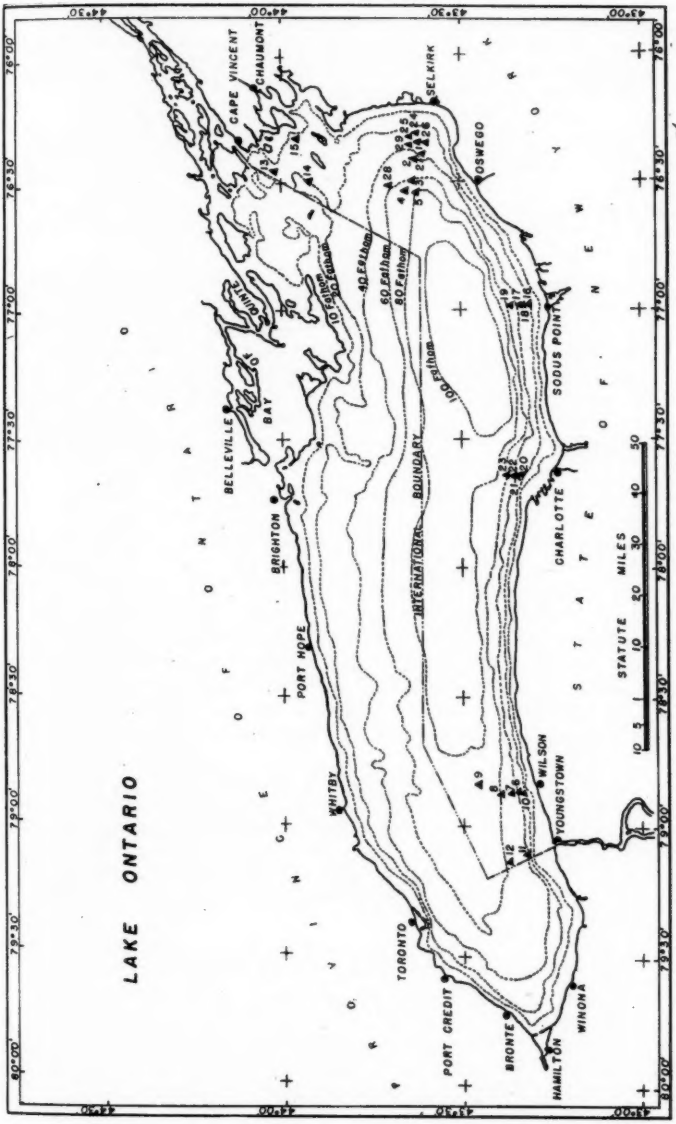

FIGURE 1.—Location of twenty-nine lifts of cisco nets indicated by small black triangles with appropriate record numbers.

one pound weight at the end of the experimental fishing and an average shrinkage value of 3/32 of an inch was found. Each net was 200 feet in length and there were two nets of each mesh size, totalling 2,000 feet for the entire gang. Specifications of the nets were: twine, 80/6-cord cotton; double selvage; side line, No. 120 soft maitre; meshes deep (2⅜-, 2½-, 2⅝-inch mesh) 26; meshes deep (2¾-, 2⅞-inch mesh), 22. The nets were made under the supervision of W. S. Cahill, cisco fisherman, Oswego, New York. Each net was strung so that it was taken up about 3/16 of an inch over one-half. In other words, to make one net 200 feet in length slightly more than 400 feet of twine were used.

All sets were made on the bottom with the nets of various size mesh arranged in the same order each side of the middle so as to overcome the possible effect of a school of fish striking one part of the gang more than another. The numbers of ciscoes taken by each mesh size in Net 1 and Net 2, respectively were: 2⅜, 392 and 400; 2½, 298 and 299; 2⅝, 242 and 209; 2¾, 125 and 173; 2⅞, 119 and 136. These data indicate that efficiency of the nets in catching fish was related to the size of mesh rather than to random chance in intercepting schools of fish.

Twenty-seven lifts were made with the experimental nets between June 20 and August 27 out of seven ports on Lake Ontario as follows: Youngstown, 2; Wilson, 5; Charlotte, 4; Sodus Point, 4; Oswego, 5; Selkirk, 4; and Chaumont, 3. Two additional lifts were made out of Oswego on November 5 and 15, respectively, but they do not enter into the calculations of efficiency of nets or average lengths and weights.

The location of each of the twenty-nine lifts is represented by a small black triangle with appropriate record number in Figure 1. Data on the time fished, date, and depth for each set are given in Table 1. No attempt was made to standardize the length of time the nets were to be set before each lift as weather conditions made this impractical.

The study of the bloater is based on a total of 2,231 specimens of which the total lengths and weights were taken on 2,229 and 1,283 individuals, respectively. The total length was measured from the tip of the snout to the tip of the tail with the dorsal and ventral rays of the caudal fin held parallel. All lengths and weights were taken from fresh specimens in the field. Sex and maturity were determined for all but six fish.

Samples of 182 bloaters taken (June 18 to July 2) off Oswego, 245 taken (July 8 to 16) off Wilson and 13 taken (May 18 to 20) off Wilson were used for the studies on age and growth. The scales were projected at a magnification of 40 diameters and measurements were made by placing a millimeter ruler along the diameter of the scale so that it bisected the posterior area. The methods used for determining age and calculating growth are given by Stone (1938).

TABLE 1.—*Locality, date, time fished, depth of capture, and the number of specimens of each species for each of the twenty-nine lifts made on Lake Ontario from June 20 to November 15, 1942*

Locality	Record No.	Date	No. nights out	Depth in fathoms	Species													
					Chubs	Lake herring	Common whitefish	Round whitefish	Lake trout	Yellow perch	Blue pike-perch	Smelt	Common sucker	Fine-scaled sucker	Alewife	Deep water sculpin	Northern sculpin
Oswego	1	June 20	2	30	47	4	....	....	....	....	....	....	....	....	....	....	....
do.	2	June 22	2	50	68	5	....	....	....	....	....	....	....	....	1	1	....
do.	3	June 25	3	60	313	1	....	....	....	....	....	....	....	....	....	....	....
do.	4	June 30	3	70	68	....	....	....	....	....	....	....	....	....	....	....	....
do.	5	July 2	2	80	8	....	....	....	....	....	....	....	....	....	....	....	....
Wilson	6	July 8	2	30	237	6	....	....	....	....	....	....	....	....	....	....	....
do.	7	July 10	2	50	130	1	....	....	....	....	....	....	....	....	....	1	....
do.	8	July 13	3	60	340	....	....	....	....	....	....	....	....	....	....	2	....
do.	9	July 16	3	67-68	63	....	....	....	....	....	....	....	....	....	....	2	....
do.	10	July 17	1	19-26	101	8	....	....	....	....	....	....	....	....	....	....	3
Youngstown	11	July 21	3	27-35	94	1	....	....	....	....	....	....	....	....	....	....	....
do.	12	July 23	2	56-58	26	....	....	....	....	....	....	....	....	....	....	1	....
Cape Vincent	13	July 29	2	24	12	....	....	....	....	....	....	....	....	....	7	....	3
do.	14	July 30	1	16-18	1	1	....	....	1	....	....	1	....	....	8	....	....
do.	15	Aug. 1	2	14-15	....	26	11	....	....	1	....	5	....	....	7	....	....
Sodus Point	16	Aug. 5	1	20-25	7	27	....	1	....	....	....	....	1	4	14	....	....
do.	17	Aug. 6	1	32-34	74	3	....	....	....	....	....	....	....	....	....	....	....
do.	18	Aug. 7	1	24-29	30	4	....	....	....	....	....	....	....	....	....	....	....
do.	19	Aug. 10	3	49-56	171	5	....	....	....	....	....	....	....	....	....	4	....
Charlotte	20	Aug. 12	1	23-25	25	3	....	....	....	....	....	....	....	....	2	....	6
do.	21	Aug. 13	1	32-35	18	1	....	....	....	....	....	....	....	....	....	....	....
do.	22	Aug. 14	1	48-49	19	....	....	....	....	....	....	....	....	....	1	1	....
do.	23	Aug. 17	3	53-60	153	....	....	....	....	....	....	....	....	....	....	2	....
Selkirk	24	Aug. 20	1	21-25	15	2	....	....	....	....	....	....	....	....	....	....	....
do.	25	Aug. 22	2	26	34	14	....	....	....	....	....	....	....	....	1	....	....
do.	26	Aug. 25	3	29-30	112	25	....	....	....	....	....	....	....	....	10	....	2
do.	27	Aug. 27	2	34-35	81	9	....	....	....	....	....	....	....	....	....	....	....
Oswego	28	Nov. 5	5	58	116	....	....	....	....	....	....	....	....	....	148	11	....
do.	29	Nov. 15	7	30	1	....	....	....	....	2	40	4	....	2	97	....	....
Total number					2,364	146	11	1	1	3	40	10	1	6	296	25	14

Analysis of the Catch of Ciscoes and Associated Species

The numbers of ciscoes according to species taken by the nets of different size mesh for each of the twenty-seven lifts made on Lake Ontario from June 20 to August 27 are shown in Table 2. A total of 2,393 ciscoes was taken. The catch consisted of *hoyi* (93.23 per cent), *kiyi* (0.50 per cent), *reighardi* (0.17 per cent), *artedi artedi* (2.29 per cent) and *artedi albus* (3.80 per cent).

For the proper management of the cisco fishery it is important to consider the characteristics of the different species of ciscoes and other food fishes associated with them. The deep water ciscoes are characterized as follows:

Bloater (*Leucichthys hoyi*).—The bloater is the predominant cisco of the deep water, 30 to 80 fathoms based on experimental netting. The bulk of the commercial catch of deep water ciscoes from New York waters consists of this species. It is a small fish which seldom reaches a weight of more than eight ounces while the average weight is four to five ounces. The largest individual taken by the experimental gear was 13.3 inches in total length and weighed 13.7 ounces. The bloater has soft flesh, is usually fat and is well suited to smoking. In Canadian waters, however, its quality and condition are regarded as poor (Pritchard 1931).

Ontario kiyi (*Leucichthys kiyi orientalis*).—Very few specimens (less than 1 per cent of the catch) among the ciscoes taken by the experimental nets could be definitely referred to this species. Kiyi resembles the bloater in size and value. The largest kiyi taken was 12.8 inches in total length and weighed 10.7 ounces. This species is more important in the Canadian waters of Lake Ontario, especially in the western end of the lake where it is fished at a depth of about 70 fathoms (Pritchard 1931). As far as mesh size considerations are concerned kiyi may be grouped with the bloater.

Shortnose chub (*Leucichthys reighardi reighardi*).—This species is often called greaser by the fishermen in reference to its very fat flesh. It is an excellent smoking fish. Small catches are made in New York waters during the spring when the fish is on the bottom for spawning. At other seasons of the year this chub evidently swims well off the bottom since very few are taken in the cisco nets. All specimens observed in the commercial catches and those taken by the experimental nets came from depths between 25 and 56 fathoms. The size of this species is somewhat larger than the bloater or the kiyi. However, no immature specimens were taken by the experimental gear.

At least two races of the shoal-water cisco or herring occur in Lake Ontario as follows:

Lake herring (*Leucichthys artedi artedi*).—This fish is a shallow water form which is most abundant at depths of less than 30 fathoms. It is little esteemed for smoking as the flesh is dry. The lake herring reaches a weight of several pounds.

TABLE 2.—*The numbers of ciscoes of each species taken in the nets of different size mesh for each of the twenty-seven lifts made on Lake Ontario from June 20 to August 27, 1942*

	Bloater *L. hoyi*					Kiyi *L. kiyi orientalis*					Shortnose chub *L. reighardi reighardi*					Lake herring *L. artedi artedi*					Lake herring *L. artedi albus*				
Record No.	2⅜"	2½"	2⅝"	2¾"	2⅞"	2⅜"	2½"	2⅝"	2¾"	2⅞"	2⅜"	2½"	2⅝"	2¾"	2⅞"	2⅜"	2½"	2⅝"	2¾"	2⅞"	2⅜"	2½"	2⅝"	2¾"	2⅞"
1	14	10	16	5	2	....	....	....	....	....	....	....	....	....	....	....	....	....	1	1	....	....	1	1	....
2	27	9	15	8	9	....	....	....	....	....	....	....	....	....	....	1	....	....	1	....	....	1	....	1	1
3	110	64	64	37	36	....	....	....	2	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....
4	24	14	11	7	12	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
5	5	1	1	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
6	86	67	46	28	10	....	....	....	....	....	....	....	....	....	....	1	....	....	....	2	1	2	....	....	....
7	39	35	29	13	14	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....
8	116	91	47	49	37	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
9	22	16	6	6	12	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
10	36	26	18	9	12	....	....	....	....	....	....	....	....	....	....	....	2	1	1	1	1	....	....	1	1
11	23	32	17	10	12	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....
12	10	5	3	1	7	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
13	4	4	3	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
14	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1
15	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2	2	3	2	3	5	4	4	1	....
16	4	....	2	1	....	....	....	....	....	....	....	....	....	....	....	2	2	4	....	....	1	1	5	6	6
17	30	14	17	10	3	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	2	....
18	10	10	5	....	4	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	3
19	64	40	26	25	11	....	1	....	1	....	....	....	1	2	....	1	2	....	1	1	....	....	....	....	....
20	7	8	2	4	4	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	2	....	....
21	4	8	3	2	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....
22	6	2	3	3	4	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....
23	49	31	34	21	17	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
24	2	6	4	3	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	1	....	....
25	11	8	8	1	6	....	....	....	....	....	....	....	....	....	....	....	1	....	1	....	1	1	2	4	4
26	31	43	22	12	3	1	....	....	....	....	....	....	....	....	....	2	2	1	....	1	3	5	3	1	7
27	33	19	14	9	3	....	2	....	....	1	....	....	....	....	....	....	1	3	1	....	....	....	1	1	2
Total number	767	564	416	264	220	2	3	2	4	1	....	1	1	2	....	9	15	13	9	9	14	14	19	19	25
Percentage of each species	93.23					0.50					0.17					2.29					3.80				

Lake herring (*Leucichthys artedi albus*).—This race includes the herring which are of greater body depth than the typical, slender *artedi* form. They cannot be distinguished readily from the Lake Erie cisco. These herring are of good quality for smoking. They were taken as deep as 60 fathoms but they are most abundant at depths of less than 30 fathoms.

While most herring could be sorted as either *artedi* or *albus* it is not maintained that the distinction is worthy of subspecific rank. There appears to be wide variation in the deep-bodied form but all variants of this form were classed as *albus* for the purposes of this study.

Since the lake herring grow to a much greater size than the deep water ciscoes it would seem undesirable to set small mesh nets where they would take immature herring in considerable numbers. Experimental netting showed that small herring (under 12 inches in total length) were relatively scarce in water deeper than 30 fathoms for they comprised less than 1 per cent of the total catch of ciscoes. Thus if the small mesh nets were prohibited in waters shallower than 30 fathoms the chance of taking young herring would be negligible.

The fish associated with the ciscoes and the depths at which they were taken are given in Table 1. Among the food fishes which might be endangered in their immature stages by the small mesh cisco nets are the lake trout (Cristivomer namaycush), common whitefish (*Coregonus clupeaformis*), and the round whitefish (*Prosopium cylindraceum quadrilaterale*). However, experimental netting and observation of commercial cisco fishing indicated that young lake trout were exceedingly scarce in New York waters of Lake Ontario. All of the lake trout taken came from depths of less than 30 fathoms. Both the common whitefish and round whitefish were taken in relatively shallow water. The occurrence of yellow perch (*Perca flavescens*), blue pike-perch (*Stizostedion vitreum glaucum*), and the fine-scaled sucker (*Catostomus catostomus catostomus*) in the catch on November 15, from 30 fathoms of water (see record No. 29) was exceptional and was no doubt due to heavy seas which drove these fish out beyond their usual depth range. Other species taken by the experimental gear were: Smelt (*Osmerus mordax*), common sucker (*Catostomus commersonnii commersonnii*), alewife (*Pomolobus pseudo-harengus*), deep water *sculpin* (*Triglopsis thompsonii*), and the northern sculpin (*Cottus cognatus*). At depths greater than 30 fathoms the ciscoes are associated principally with the alewife, and the deep water sculpin.

The alewife which is known to occur in considerable abundance in Lake Ontario may compete seriously with the deep water ciscoes when in their habitat. This conclusion is supported by an analysis of the food of 24 alewives (167 to 280 millimeters in total length) taken at a depth of 58 fathoms on November 5, 1942, off Oswego (record No. 28). The bulk of the food consisted of *Mysis relicta* (99.71 per cent by volume) while *Pontoporeia hoyi* (0.04 per cent) and undetermined re-

TABLE 3.—*Summary of the total number, percentage, average number per net, and average length and weight for the sexes combined, and the number of individuals of each sex of the bloater (L. hoyi) taken in the nets of different size mesh for 27 lifts made on Lake Ontario from June 20 to August 27, 1942*[1]

Character	Mesh size in inches				
	2⅜	2½	2⅝	2¾	2⅞
Total number ..	767	564	416	264	220
Percentage	34.38	25.28	18.65	11.83	9.86
Average number per net	14.2	10.4	7.7	4.9	4.1
Average total length (millimeters)	253.9 (766)	257.5	260.3	252.6	249.7 (219)
Average total length (inches)	9.99	10.14	10.25	9.94	9.83
Average weight (grams)	137.9 (390)	141.5 (307)	146.8 (305)	137.8 (130)	118.6 (151)
Average weight (ounces)	4.86	4.99	5.18	4.86	4.18
Males, total number[2]	168	83	65	45	42
Females, total ....number[2]	598	477	351	219	177

[1]Number of individuals used for averages are indicated in parentheses when lower than the total number.
[2]Sex undetermined for six fish.

mains (0.25 per cent) comprised the remainder of the stomach contents. Examination of the food of the deep water ciscoes showed the main items to consist of *Mysis relicta* and *Pontoporeia hoyi* which agrees with the findings of Pritchard (1931).

EFFICIENCY OF THE NETS OF DIFFERENT SIZE MESH

A summary of the total number, average number per net and the average length and weight of the bloaters taken by the nets of each mesh size is shown in Table 3. The percentage of the total number for each mesh size shows the following order of efficiency of nets: 2⅜, 34.38; 2½, 25.28; 2⅝, 18.65; 2¾, 11.83 and 2⅞, 9.86. The 2⅜-inch net was the most efficient size for the bloater based on the total number of individuals caught and on the average number per net, while as one proceeds from the 2⅜-inch net to the larger mesh sizes the catch was successively smaller. On a poundage basis considering the 2¾-inch mesh as a standard, the catch was as follows: 2⅜, 2.8; 2½, 2.3; 2⅝, 1.6; 2¾, 1.0; and 2⅞ inch, 0.7. Thus a change in regulations to the 2½-inch mesh would allow the fishermen to take 2.3 times the poundage of bloaters that the 2¾-inch gear takes.

The fish taken by the 2¾-inch net averaged smaller in total length and weight than those caught in each of the three smaller mesh sizes while the fish which averaged largest were taken by the 2⅝-inch nets. Van Oosten (1929) obtained similar results with the bloater (*hoyi*) of Lake Michigan. He found that the bloater averaged slightly more in length and weight in the 2½-inch net than in the 2¾-inch net.

A length-frequency distribution of the bloaters according to the nets of each mesh size is presented in Table 4. The larger mesh sizes, 2¾ inch and 2⅞ inch, seem to take more of the extreme sizes of fish than

the smaller mesh nets. Many of the smaller specimens taken by the 2¾- and 2⅞-inch gear are not gilled in the regular manner but are entangled by a thread in the mouth and around the maxillary.

TABLE 4.—*Length-frequency distribution of the bloater (L. hoyi) according to the nets of different size mesh (collections combined)*

Total length interval (millimeters)	Mesh size in inches					
	2⅝	2½	2⅝	2¾	2⅞	2⅝-2⅞
150-154	1	....	....	....	....	1
155-159	....	....	....	....	1	1
160-164	....	....	....	....	....	....
165-169	....	....	....	....	....	....
170-174	1	....	....	....	....	1
175-179	....	....	....	....	....	....
180-184	....	1	....	....	....	1
185-189	....	....	....	....	....	....
190-194	3	1	....	2	1	7
195-199	....	1	2	3	1	7
200-204	2	4	3	7	1	17
205-209	4	2	7	6	9	28
210-214	4	1	4	7	7	23
215-219	7	4	7	8	7	33
220-224	17	14	11	17	20	79
225-229	26	17	9	12	15	79
230-234	42	20	15	14	20	111
235-239	40	28	22	15	13	118
240-244	74	39	24	15	19	171
245-249	86	45	24	9	11	175
250-254	92	55	24	18	8	197
255-259	81	65	38	17	6	207
260-264	86	62	35	14	11	208
265-269	58	53	35	16	4	166
270-274	43	40	41	16	12	152
275-279	36	42	32	16	13	139
280-284	19	31	27	17	5	99
285-289	18	19	15	12	10	74
290-294	12	10	8	13	6	49
295-299	3	4	17	5	3	32
300-304	6	3	7	3	7	26
305-309	2	....	3	....	5	10
310-314	1	1	4	1	2	9
315-319	2	....	....	1	....	3
320-324	....	....	2	....	2	4
325-329	....	1	....	....	....	1
330-334	....	1	....	....	....	1
Total number	766	564	416	264	219	2,229
Average total length (millimeters)	253.87	257.54	260.25	252.56	249.73	.....

CONDITION AND AVERAGE LENGTH AND WEIGHT

Preliminary observations on the commercial catches of bloaters indicated that they varied somewhat in quality and condition. This variation was from fat fish of good quality for smoking to emaciated individuals which were practically worthless. Thus the following criteria of condition based on a general observation of the external and internal appearance of the fish were set up: A condition refers to fat fish in excellent condition; B condition refers to fish in fair to good condition and more or less intermediate; while C condition refers to emaciated fish in very poor condition. The difference between A condition and C condition fish were obvious while the distinction between A and B condition specimens was more difficult to make. The C condition

bloaters are not shipped to the smokers. The fishermen usually throw them away or bring them back to the dock where they are given away. The numbers and percentages of A, B and C condition bloaters taken by the nets of different size mesh are given in Table 5. The percentage of C condition fish increases successively as one proceeds from the smallest to the largest mesh size. On the basis of experimental netting 12.98 per cent of the bloater were of C condition. An analysis of 4,650 bloaters taken by commercial fishermen out of Oswego showed 15.39 per cent of the fish to be C condition individuals. They were taken by 2¾- and 3- inch mesh nets.

TABLE 5.—*The number and percentage of A, B, and C condition specimens of the bloater (L. hoyi) taken in the nets of different size mesh (collections combined)*[1]

Mesh size in inches	Condition A		Condition B		Condition C	
	Number	Percentage	Number	Percentage	Number	Percentage
2⅜	431	56.41	280	36.65	53	6.94
2½	372	66.31	142	25.31	47	8.38
2⅝	234	59.09	94	23.74	68	17.17
2¾	138	52.27	69	26.14	57	21.59
2⅞	95	43.38	63	28.77	61	27.85
2⅜-2⅞	1,270	57.62	648	29.40	286	12.98

[1]The following criteria of condition were used: A = excellent condition, fat; B = fair to good condition, intermediate; C = poor condition, emaciated.

A comparison of average total lengths and weights and the percentage of A, B and C condition specimens for the bloaters taken at various localities on Lake Ontario is presented in Table 6. The averages indicate that fish taken off Oswego are somewhat larger and in better condition than those caught in the other areas sampled. There seems to be a successive decrease in the average weight of the fish taken out of the various ports as one proceeds from Oswego to Youngstown although the differences are slight.

Sex Ratio and Maturity

Of the 2,225 bloaters which were sexed 81.89 per cent were females while 18.11 per cent were males, a sex ratio of 4.5:1. This predominance of females held true for the fish taken in the nets of each mesh size as may be seen from Table 3. In each of the twenty-seven lifts made from June 20 to August 27 the females outnumbered the males.

Practically all of the bloaters taken by the experimental nets were mature individuals. Only in a few specimens was the stage of maturity uncertain. According to the findings of Pritchard (1931) the bloater becomes ripe in many cases in the fall of its second year and large numbers are sexually mature in their third year.

Age and Growth

Examination of scale samples taken at intervals from May 19 to November 15 showed that the resumption of growth and annulus formation occur late in the season. Evidence of growth resumption first appeared on the scales about the middle of August. In the scales

TABLE 6.—*Comparison of average total lengths, average weights, and the percentages of A, B and C condition specimens of bloaters (L. hoyi) taken at various localities on Lake Ontario (collections combined)*[1]

Locality	Average total length (millimeters)	Average total length (inches)	Average weight (grams)	Average weight (ounces)	Condition[2]		
					Percentage A	Percentage B	Percentage C
Youngstown and Wilson	253.3 (989)	9.97	128.8 (412)	4.54	54.41 (537)	28.77 (284)	16.82 (166)
Charlotte	249.8 (212)	9.83	130.8 (212)	4.61	56.60 (120)	26.42 (56)	16.98 (36)
Sodus	254.5 (276)	10.02	143.8 (275)	5.07	58.76 (161)	30.29 (83)	10.95 (30)
Oswego	259.9 (739)	10.23	147.7 (311)	5.21	61.69 (443)	30.78 (221)	7.52 (54)

[1]Numbers of individuals used for averages and percentages are indicated in parentheses.
[2]The following criteria of condition were used: A = excellent condition, fat; B = fair to good condition, intermediate; C = poor condition, emaciated.

used for age and growth determinations growth resumption had not yet taken place and the last annulus was at the edge of the scale.

Table 7 presents a length-frequency distribution of the bloater according to age groups III to XI which was the range represented by the fish sampled. The data show that length is a poor index of age since fish of some lengths could belong to any one of five or six different age groups.

TABLE 7.—*Length-frequency distribution of the bloater (L. hoyi) according to age group (sexes combined)*[1]

Total length interval (millimeters)	Age group									
	III	IV	V	VI	VII	VIII	IX	X	XI	III-XI
190-194	....	1	....	....	....	....	....	....	....	1
195-199	....	....	....	....	....	....	....	....	....	....
200-204	1	4	....	....	....	....	....	....	....	5
205-209	....	3	1	....	....	....	....	....	....	4
210-214	....	2	2	....	....	....	....	....	....	4
215-219	1	5	3	1	....	....	....	....	....	10
220-224	....	5	7	6	3	....	....	....	....	21
225-229	....	2	10	8	2	....	....	....	....	22
230-234	....	1	6	1	8	2	....	....	....	18
235-239	....	3	7	4	6	1	....	....	....	21
240-244	....	2	6	11	7	1	....	....	....	27
245-249	....	....	7	9	17	2	1	....	....	36
250-254	....	1	3	10	7	10	4	1	....	36
255-259	....	....	1	7	14	10	1	....	....	33
260-264	....	....	1	2	10	14	2	....	....	29
265-269	....	1	3	4	17	7	4	....	....	36
270-274	....	....	1	4	11	13	4	1	....	34
275-279	....	....	1	1	7	9	7	1	....	26
280-284	....	....	1	2	6	9	3	....	....	21
285-289	....	....	....	3	2	3	7	1	....	16
290-294	....	....	....	....	1	3	5	1	1	11
295-299	....	....	....	1	2	3	3	2	....	11
300-304	....	....	....	....	1	1	4	3	....	9
305-309	....	....	....	....	....	1	....	....	....	1
310-314	....	....	....	....	1	....	2	....	....	3
315-319	....	....	....	....	....	....	2	1	....	3
320-324	....	....	....	....	....	....	1	....	....	1
325-329	....	....	....	....	....	....	....	....	....	....
330-334	....	....	....	....	....	....	....	....	....	....
335-339	....	....	....	....	....	....	....	....	1	1
Total number	2	30	60	74	122	89	50	11	2	440
Pecentage in sample	0.5	6.8	13.6	16.8	27.7	20.2	11.4	2.5	0.5	....

[1]Samples taken off Oswego and Wilson, New York are combined.

A comparison of bloaters taken off Oswego and off Wilson, with respect to average total length and weight for the males and females of each age group is made in Table 8. The absence of males from age groups above IX in both of the areas sampled suggests that they may be shorter lived than the females. Age groups V to VIII predominated in the samples from each locality while the modes of the distributions fell in age group VII. On the basis of the scales studied the bloater enters the fishery during its fourth or fifth year of life. These fish would probably have spawned at least once. It is apparent that the bloater attains most of its growth in weight after the fifth and sixth year of life as seen from the data of Table 8. The females seem to average heavier than the males in most age groups and attain a greater maximum weight.

TABLE 8.—*Comparison of Lake Ontario Bloaters (L. hoyi) taken off Oswego and off Wilson, New York with respect to average total length and weight for the males and females of each age group*[1]

Locality	Sex	Character	Age group III	IV	V	VI	VII	VIII	IX	X	XI	III-XI
Oswego	Female	Total length (millimeters)	209.5	237.1	231.7	254.2	262.3	267.9	279.4	298.3	337.0	262.5
			(2)	(8)	(14)	(14)	(41)	(39)	(20)	(7)	(1)	(146)
		Total length (inches)	8.3	9.3	9.1	10.0	10.3	10.5	11.0	11.7	13.3	10.3
		Weight (grams)	59.0	82.8	74.9	126.6	146.3	159.3	175.5	246.3	389.0	146.2
			(1)	(5)	(9)	(8)	(21)	(19)	(14)	(3)	(1)	(81)
		Weight (ounces)	2.1	2.9	2.6	4.5	5.2	5.6	6.2	8.7	13.7	5.2
	Male	Total length (millimeters)	.....	212.0	216.0	254.5	258.7	269.4	290.8	.....	.....	259.4
			.....	(3)	(1)	(4)	(15)	(9)	(4)	.....	.....	(36)
		Total length (inches)	.....	8.4	8.5	10.0	10.2	10.6	11.5	.....	.....	10.2
		Weight (grams)	.....	67.0	82.0	137.0	145.2	151.4	240.0	.....	.....	143.9
			.....	(2)	(1)	(3)	(5)	(5)	(2)	.....	.....	(18)
		Weight (ounces)	.....	2.4	2.9	4.8	5.1	5.3	8.5	.....	.....	5.1
Wilson	Female	Total length (millimeters)	.....	217.6	240.9	248.8	256.9	271.1	282.1	276.0	294.0	254.8
			.....	(15)	(39)	(46)	(55)	(30)	(24)	(4)	(1)	(214)
		Total length (inches)	.....	8.6	9.5	9.8	10.1	10.7	11.1	10.9	11.6	10.0
		Weight (grams)	.....	70.4	109.1	118.9	140.6	169.0	190.9	193.9	231.0	136.3
			.....	(15)	(39)	(46)	(55)	(30)	(24)	(4)	(1)	(214)
		Weight (ounces)	.....	2.5	3.9	4.2	5.0	6.0	6.7	6.8	8.2	4.8
	Male	Total length (millimeters)	.....	209.8	231.8	239.0	250.4	258.6	288.5	.....	.....	245.4
			.....	(4)	(6)	(10)	(11)	(11)	(2)	.....	.....	(44)
		Total length (inches)	.....	8.3	9.1	9.4	9.9	10.2	11.4	.....	.....	9.7
		Weight (grams)	.....	60.8	107.9	97.6	119.8	142.7	194.8	.....	.....	116.9
			.....	(4)	(6)	(10)	(11)	(11)	(2)	.....	.....	(44)
		Weight (ounces)	.....	2.1	3.8	3.4	4.2	5.0	6.9	.....	.....	4.1

[1]Numbers of individuals used for averages are indicated in parentheses.

In general the scales show a good growth in length during the first year of life, the second year a fair to good growth, and the third year a fair to poor growth. After the third year many of the scales indicate a badly stunted condition from which some of the fish never recovered while others, particularly the females, show marked acceleration in growth during the later years of life. A very important problem which has yet to be solved is why fish are stunted.

The calculated lengths of Tables 9, 10 and 11 do not exhibit the stunted condition so clearly as an examination of the individual scales discloses. This is apparently due to the differences in the year of life at which recovery from the stunted condition takes place, which tends to smooth out the averages and results in a fairly uniform annual increment after the third year of life. Comparison of the calculated lengths of Tables 9, 10 and 11 show fish of most age groups taken off Oswego, to average slightly longer than those taken off Wilson. There seems to be little difference in the growth in length of the males and females during the first six years of life. However, the females which apparently are longer lived attain a greater maximum growth in length than the males.

Conversion Factors for Length and Weight

Since statistics of the cisco catch are usually based on the dressed weight of the fish it seems desirable to ascertain the relationship between round weight (weight of fish as caught) and dressed weight (weight of gutted fish as shipped to the smokers). Factors for the conversion of round weight to dressed weight, and the reverse, for bloaters of various condition and for the two races of lake herring are given in Table 12. A factor for the conversion of total length to standard length is also given for the bloaters.

Summary

1. The deep water ciscoes are fat fish of type adapted to smoking. In Lake Ontario they are: bloater (*Leucichthys hoyi*), kiyi (*Leucichthys kiyi orientalis*), and shortnose chub (*Leucichthys reighardi reighardi*).

2. The experimental gear consisted of cotton gill nets of the following mesh sizes: 2⅜, 2½, 2⅝, 2¾ and 2⅞ inch. Each net was 200 feet in length and there were two nets of each mesh size, totaling 2,000 feet for the entire gang. Twenty-nine lifts were made between June 20 and November 15, 1942 out of seven ports on Lake Ontario.

3. The study of the bloater is based on 2,231 specimens of which the total lengths and weights were taken on 2,229 and 1,283 individuals, respectively. Samples of 182 bloaters taken (June 18 to July 2) off Oswego, 245 taken (July 8 to 16) off Wilson and 13 taken May 18 to 20) off Wilson were used for the studies of age and growth.

4. A total of 2,393 ciscoes and lake herring was taken. The catch consisted of *hoyi*, 93.23 per cent; *kiyi*, 0.50 per cent; *reighardi*, 0.17

TABLE 9.—*Average calculated total lengths at the end of each year of life of various age groups of the bloater (L. hoyi) represented in a sample of 146 female specimens taken from Lake Ontario off Oswego, New York*

No. of specimens	Year class	Age group	Total length at capture (millimeters)	Calculated length in millimeters at end of year of life										
				1	2	3	4	5	6	7	8	9	10	11
1	1931	XI	337.0	77	98	136	165	187	206	226	245	273	298	337
7	1932	X	298.3	93	137	156	177	195	214	233	254	273	298	.....
20	1933	IX	279.4	95	133	159	179	198	218	236	257	279	.....	.....
39	1934	VIII	267.9	92	136	162	183	201	219	239	268	.....	.....	.....
41	1935	VII	262.3	94	148	172	191	212	233	262	.....	.....	.....	.....
14	1936	VI	254.2	91	143	169	194	220	254	.....	.....	.....	.....	.....
14	1937	V	231.7	100	166	189	211	231	.....	.....	.....	.....	.....	.....
8	1938	IV	237.1	111	178	207	237	.....	.....	.....	.....	.....	.....	.....
2	1939	III	209.5	103	185	209	.....	.....	.....	.....	.....	.....	.....	.....
Grand average calculated length				95	145	170	190	208	227	247	263	278	299	337
Grand average annual increment				95	50	25	20	18	19	20	16	15	21	38
Number of specimens				146	146	146	144	136	122	108	67	28	8	1

TABLE 10.—*Average calculated total lengths at the end of each year of life of various age groups of the bloater (L. hoyi) represented in a sample of 214 female specimens taken from Lake Ontario off Wilson, New York*

No. of specimens	Year class	Age group	Total length at capture (millimeters)	Calculated length in millimeters at end of year of life										
				1	2	3	4	5	6	7	8	9	10	11
1	1931	XI	294.0	95	122	135	153	164	180	205	228	245	271	294
4	1932	X	276.0	80	109	134	157	177	197	214	233	251	276	.....
24	1933	IX	282.1	82	123	148	171	191	212	233	255	282	.....	.....
30	1934	VIII	271.1	88	131	159	184	204	222	242	271	.....	.....	.....
55	1935	VII	256.9	93	137	163	185	207	227	257	.....	.....	.....	.....
46	1936	VI	248.8	97	144	171	196	219	248	.....	.....	.....	.....	.....
39	1937	V	240.9	96	156	186	211	241	.....	.....	.....	.....	.....	.....
15	1938	IV	217.6	106	166	194	217	.....	.....	.....	.....	.....	.....	.....
Grand average calculated length				93	141	168	192	213	229	246	262	277	275	294
Grand average annual increment				93	48	27	24	21	16	17	16	15	.....	19
Number of specimens				214	214	214	214	199	160	114	59	29	5	1

TABLE 11.—*Comparison of Lake Ontario Bloaters (L. hoyi) taken off Oswego and off Wilson, New York, with respect to grand average calculated lengths for each sex*[1]

Locality	Sex	Calculated total length in millimeters at end of year of life										
		1	2	3	4	5	6	7	8	9	10	11
Oswego	Female	94.7 (146)	144.7 (146)	169.8 (146)	190.4 (144)	208.4 (136)	227.3 (122)	246.7 (108)	263.0 (67)	277.5 (28)	298.5 (8)	337.0 (1)
	Male	95.3 (36)	140.7 (36)	168.5 (36)	191.3 (36)	209.6 (33)	232.5 (32)	252.9 (28)	269.8 (13)	290.0 (4)	.....	.....
Wilson	Female	93.0 (214)	140.8 (214)	167.9 (214)	191.6 (214)	212.8 (199)	228.9 (160)	245.9 (114)	261.5 (59)	276.5 (29)	275.1 (5)	294.0 (1)
	Male	91.3 (44)	136.3 (44)	166.6 (44)	188.7 (44)	207.7 (40)	224.1 (34)	242.3 (24)	259.5 (13)	288.0 (2)	.....	.....
Samples combined	Female	93.7 (360)	142.4 (360)	168.7 (360)	191.1 (358)	211.0 (335)	228.2 (282)	246.3 (222)	262.3 (126)	276.9 (57)	289.5 (13)	315.0 (2)
	Male	93.1 (80)	138.3 (80)	167.4 (80)	189.9 (80)	208.6 (73)	227.7 (66)	247.9 (52)	264.6 (26)	290.0 (6)	.....	.....

[1]Numbers of individuals used for averages are indicated in parentheses.

TABLE 12.—*Factors for the conversion of total length to standard length, round weight to dressed weight and dressed weight to round weight of Lake Ontario ciscoes*[1]

Species	Condition[4]	Conversion factors			
		No. of specimens	Total length (millimeters) to standard length (millimeters)	Round weight (grams) to dressed weight (grams)	Dressed weight[3] (grams) to round weight[2] (grams)
L. hoyi	A	78	.....	0.8404	1.1899
do.	B	55	.....		
do.	C	17	.....	0.8598	1.1630
do.	A-C	150	0.8058	0.8658	1.1550
			[3](79)	0.8477	1.1797
L. a. artedi	A	13	.....	0.9031	1.1073
L. a. albus	A	21	.....	0.8822	1.1336

[1]Total length interval in millimeters (207-289); weight intervals in grams: *hoyi* (66-325), *artedi* (166-430), *albus* (305-935).
[2]Round weight refers to fish as taken; dressed weight refers to gutted fish as shipped to the smokers.
[3]Number of fish employed.
[4]The following criteria of condition were used: A = excellent condition, fat; B = fair to good condition, intermediate; C = poor condition, emaciated.

per cent; *artedi artedi,* 2.29 per cent; and *artedi albus,* 3.80 per cent.

5. The danger of cisco nets to young lake trout, whitefish and lake herring was found to be negligible if the nets were set at depths of 30 fathoms or more.

6. Ciscoes in the deep water are associated principally with the deep water sculpin and the alewife. Analysis of the food of ciscoes and alewives indicated competition between them.

7. The per centage of bloaters taken by the nets of each mesh size showed the following order of efficiency of nets: 2⅜, 34.38; 2½, 25.28; 2⅝, 18.65; 2¾, 11.83; and 2⅞ inch 9.86. On a poundage basis considering the 2¾ inch mesh as a standard the catch was 2⅜, 2.8; 2½, 2.3; 2⅝, 1.6; 2¾, 1.0; and 2⅞ inch, 0.7.

8. Bloaters taken by the 2¾ and 2⅞ inch nets averaged smaller in length and weight than those caught in each of the three smaller mesh sizes while the 2⅝ inch net took fish which averaged largest.

9. The bloaters were sorted into three categories of condition (A, B and C) based on the following criteria: A—excellent condition, fat; B—fair to good condition, intermediate, and C—poor condition, emaciated. The percentages of C condition fish taken by the nets of different size mesh increased successively, proceeding from the smallest to the largest mesh size. C condition fish comprised 12.98 per cent of the total catch.

10. Bloaters taken off Oswego averaged larger in length and weight and were of better average condition than those from the other areas sampled.

11. Of 2,225 bloaters 81.89 per cent were females while 18.11 per cent were males. This predominance of females held true for the nets of each mesh size. Practically all of these fish were mature.

12. Growth resumption first appeared on the scales of the bloater about the middle of August. In all of the scales used for age and growth studies the last annulus was at the edge of the scale. Age groups III to XI were represented in the scale samples while age groups V to VIII predominated. The absence of males from age groups above IX suggests that they may be shorter lived than the females.

13. The bloater enters the fishery during its fourth or fifth year of life and attains most of its growth in weight after the fifth or sixth year of life. The females average heavier than the males in most age groups and attain a greater maximum growth in weight.

14. After the third year of life many of the scales indicated a badly stunted condition from which some of the bloaters never recovered, while others, particularly the females, showed marked acceleration in growth during the later years of life.

15. Calculated lengths showed the growth of males and females to be about equal for the first six years of life. However, the females attained a greater maximum growth in length.

16. Factors for the conversion of round weight to dressed weight

and vice versa for bloaters of various condition and for the two races of lake herring are given. A factor for the conversion of total length to standard length is also shown for the bloater.

Recommendations

On the basis of the data obtained through this investigation it was recommended that the size of the mesh of gill nets used for taking ciscoes in New York waters of Lake Ontario be reduced from 2¾ inch mesh to 2½ inch mesh, measured when in use. A depth limit of not less than 180 feet of water was also specified to safeguard against the destruction of small trout, whitefish and lake herring. These recommendations, essentially in this form, were adopted in 1943.

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FOOD-CHAINS AND THE FOOD CYCLE IN HAWAIIAN FISH PONDS.—PART I. THE FOOD AND FEEDING HABITS OF MULLET (*MUGIL CEPHALUS*), MILKFISH (*CHANOS CHANOS*), AND THE TEN-POUNDER (*ELOPS MACHNATA*)[1]

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ABSTRACT

The food and feeding habits of the three most important market fish in Hawaiian ponds (*Mugil cephalus, Chanos chanos,* and *Elops machnata*) were analyzed to ascertain the position of these fish in the food-chains and the food cycle occurring within the ponds.

Mullet (*M. cephalus*) subsist primarily on littoral diatoms and blue-green algae, the presence of a unique pharyngeal filtering device prohibiting them from swallowing larger forms. No variation in food because of season or size of fish was found.

Milkfish (*C. chanos*) are also herbivores; juveniles consume unicellular and other minute algae while larger fish take an increasing amount of larger filamentous algae. Competition for food between mullet and milkfish is greater than hitherto supposed and cannot be diminished under present operational procedures.

An increased food supply for both species probably could be achieved by the application of inorganic fertilizers together with the construction of additional shallow areas in the ponds.

Ten-pounders (*E. machnata*) subsist largely on mosquito fish and shrimps; no juvenile mullet or milkfish were found in 164 specimens of various sizes taken throughout the year. This species apparently damages pond fisheries less than is commonly supposed; in fact, ten-pounders may prove an asset to the industry.

INTRODUCTION

Since legendary times Hawaiian commercial fish ponds have provided a substantial portion of the fish consumed in the archipelago. For various reasons ponds have steadily fallen into disuse, and at present, only a fraction of the original number is utilized for production of fish. The general paucity of food fish available to island residents has stimulated an investigation into the possibility of increasing the yield of existing ponds through application of appropriate fish-cultural methods. Since cultural methods are dependent upon interactions of the animal and plant complex present, an analysis of these factors must precede efforts directed toward increased production of fish. In view of the fact that each pond contains a closely interdigitated animal and plant community, it seemed desirable to approach the problem from an ecological viewpoint.

Food is one of the most important factors in the life of animals, and

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in most communities the species are arranged in food-chains which combine to form a whole food cycle. This study is directed toward an understanding of the food relationships existing in these pond communities in order to ascertain which links in the chain might be altered to increase the over-all production of commercially important fish. The first segment of the study embodied in this report concerns the food and feeding habits of the three most important market fish occurring in the ponds, mullet (*Mugil cephalus*), milkfish (*Chanos chanos*), and ten-pounders (*Elops machnata*).

For an account of the history, physical features, and operational procedures of Hawaiian fish ponds see Cobb (1903) and Bell and Higgins (1939). Young mullet are seined up along the shores and placed in ponds to be held until they have grown to a marketable size. Neither artificial propagation nor feeding of the impounded fish is practiced, whereas, in ponds in the Philippines (Herre and Mendoza, 1929) and in Java (Vos, 1941) rather careful culturing of food plants is undertaken.

The cosmopolitan, sub-tropical distribution of the genus *Mugil* and the quality of this fish as a food are reflected in the several investigations of its biology made at widely separated localities. Gunther (1880) stated that mullet feed on organic substances which are mixed up with sand and mud. He also mentioned the unique pharyngeal straining device of this group. Linton (1904) mentioned that the digestive tract contents of mullet collected near Beaufort, North Carolina, consisted of vegetable debris reduced to a pulp, in which there were immense numbers and many species of diatoms mixed with sand. Jordan (1905) stated that adult mullet feed on the bottom in quiet water, swimming head downward. The food is sifted over in the mouth, the mud rejected, and the plants, chiefly microscopic, retained. Jacot (1920) found that the food of "silvery-sided" juvenile mullet from Beaufort consisted of an almost exclusive diet of crustaceans, mainly copepods. Slightly larger "dusky" mullet consumed about 40 per cent sand and mineral matter and 60 per cent vegetable and animal matter. Of the latter, 50 per cent was diatoms, 35 per cent was other algae and other soft vegetable matter, and 15 per cent was miscellaneous animal matter. None of these food types was identified taxonomically. Herre and Mendoza (1929) state that mullet in the Philippines feed on organisms in the surface layer of the mud as well as on algae. These investigators also suggest that little or no competition between mullet and milkfish exists. In Egypt, Ghazzawi (1933) analyzed 79 stomachs of *M. cephalus* and *M. capito*. He showed the main food of adult fish to be of vegetable origin (mainly diatoms and other plants). The diatoms eaten were mostly epiphytic and littoral forms. Few planktonic types were found. In a later paper (1935) Ghazzawi described the pharynx and intestinal tract of mullet and made observations correlating the diet with the histological features and length of the intestine. Recently Kesteven (1942) remarked that

mullet in Australia fed on detritus, but he failed to identify any of the organisms or to discover the relative importance of the plant and animal constituents.

Less is known about the natural foods of the milkfish. Maxwell (1921) mentions that it is a sea and estuarine fish which feeds on "sea moss" and an alga (*Oedogonium* sp.). Its food habits as a cultivated pond fish in Malaysia and in the Philippines are well known. Maxwell described the culture of *Oedogonium* in Malayan milkfish ponds and inferred that an alga is their exclusive food. Herre and Mendoza (1929) showed that slightly different food was cultured for milkfish in Philippine ponds. A plant complex consisting of unicellular, colonial, and filamentous blue-green algae, diatoms, bacteria, unicellular green algae, and very fine threads of Chlorophyceae (*Cladophora, Spirogyra,* and *Chaetomorpha*) is cultured for fish below 35 to 50 millimeters in length. Fish of greater length feed more upon filamentous green algae (*Cladophora, Enteromorpha, Spirogyra,* and *Vaucheria*) and less on the minute types mentioned above. Vos (1941) reported on cultivation procedures of milkfish in Java inferring the algal nature of the food. No specific algal types are mentioned in the abstract available.

Virtually nothing is known about the actual food types consumed by ten-pounders. Herre and Mendoza (1929) briefly mention that it is a carnivorous and predaceous species, implying that it consumed pond milkfish. A congener, *E. affinis,* of the Salton Sea was shown by Dill and Woodhull (1942) to consume desert minnows and hydrophilid beetles.

Methods

Stomachs analyzed in this study were taken from fish collected throughout the year in several ponds on the islands of Oahu and Molokai in the Territory of Hawaii. Small fish were immediately preserved in a 15 or 20 per cent solution of formalin. The digestive tracts of larger fish were removed and preserved in separate cloth bags or containers. Prior to the analysis of the food content the length of the intestine of fish of different sizes was measured.

Most samples of mullet food were taken from the cardiac end of the stomach, which seems to function as a small crop or reservoir from which small amounts of food are passed into the minute lumen of the muscular, gizzard-like pyloric portion. The stomach contents were paced in a small vial of preservative and shaken to break up food masses and to form an even suspension in the preservative. Several drops of the suspension were immediately drawn into a pipette and transferred to a glass slide marked off in one millimeter squares. The entire slide was given a cursory examination, ten squares were selected which appeared most typical with respect to the mass of organisms present, and counts were made of the organisms present on each square. The results are expressed numerically, and the percentages

indicate the percentage of the total number of all items counted. In addition, the incidence of occurrence of items among fish examined is expressed as the percentage of the total number of fish.[2]

In carrying out the analyses of the food of milkfish the contents of an individual stomach were placed in a vial of preservative and shaken until the food materials were evenly suspended. Several drops of this suspension were then placed on a glass slide and examined microscopically. The percentage by volume of each major food group was estimated and the results are expressed as percentage of the total volume. As for mullet the percentage by incidence of occurrence among fish examined is expressed. In order to arrive at the summaries shown in the tables, each stomach was weighted according to the amount of food it contained following the method set forth by Calhoun (1944). Three degrees of fullness were recognized and defined as follows: (1) very full—walls of stomach distended with food; (2) moderately full—stomach cavity filled, or nearly so, but walls not distended; and (3) nearly empty—stomach cavity not nearly filled. The percentage of a given food in an individual stomach was multiplied by an appropriate factor (1, 2, or 3, depending on whether they fell into category 3, 2, or 1, respectively, as defined above). The resultant products were then added for all fish in a series, considering each food separately. The summation for an individual kind of food, taken as a percentage of the corresponding summation for all foods, yielded the final figures shown in the tables. This method gives, essentially, the average percentage by volume of a given food in all stomachs of a series. The weighting of the stomachs according to their degree of fullness insures that fish which have been feeding most actively will contribute more strongly to the final figure than those which have nearly empty stomachs. It also discounts the importance of nearly empty stomachs containing a few atypical organisms.

Stomachs of ten-pounders were weighted, in the manner outlined above, according to degrees of fullness. Food items were identified and counted, and an estimate was made of their percentage composition by volume within each stomach. Results are expressed as the percentage frequency of occurrence among fish examined, percentage composition by number of all items, and percentage of the total volume.

The genera of diatoms mentioned in this paper are based on those set forth by Van Heurck (1899).

Results

Mullet.—The data were analyzed with regard to size of fish and on seasonal bases but no significant difference between various groups was found. Consequently, the data for all mullet analyzed are pre-

[2]The aid of Dr. Charles J. Engard and Isabella A. Abbott of the Department of Botany, University of Hawaii, in identifying the genera of plants mentioned in this paper is gratefully acknowledged.

sented in Table 1. Mullet are transferred from the reef to the pond when they attain a standard length of 16 to 20 millimeters.

TABLE 1.—*Dietary items found in 212 stomachs of* Mugil cephalus *which ranged in size from 16.2 to 400 millimeters standard length*

Food item	Percentage of stomachs containing the item	Percentage of the total number of all items
Diatoms:		
Navicula	96	75
Cymbella	80	8
Pleurosigma	71	4
Amphora	69	4
Melosira	52	1.5
Mastogloia	45	1.3
Coscinodiscus	29	1
Nitzschia	59	1
Blue-green algae:		
Oscillatoria	19	2
Miscellaneous plant types	....	1.6
Miscellaneous animal types	....	trace[1]

[1]Less than 1 per cent.

Milkfish.—It was found that the intestine of milkfish undergoes heteronomous growth resulting in two distinct intestinal length-standard length ratios with a brief period of transition between them (see below). Since significant changes in the food habits accompanied the variation in intestinal growth, the data are presented in three tables which summarize the diet for each distinct period. Table 2 shows the dietary items consumed by young milkfish which have an intestinal length-standard length ratio similar to mullet. Table 3 indicates the food eaten during the brief transition period in which the intestine grows to its maximum length relative to body length. Table 4 summarizes the foods consumed by fish after the intestine has reached its maximum length relative to body length and henceforth maintains a growth rate commensurate with the growth of the fish. No seasonal variation in foods consumed was found. Juvenile milkfish apparently enter the ponds adjacent to the ocean through the screened gates since no effort is made by pond operators to transfer them from the reef to the ponds.

TABLE 2.—*Dietary items found in 38 stomachs of juvenile* Chanos chanos *which ranged in size from 55 to 89 millimeters standard length*

Food item	Percentage of stomachs containing the item	Percentage composition by volume
Diatoms	100	64
Navicula, Cymbella, Melosira, Nitzschia, Pleurosigma, Mastogloia, Coscinodiscus, Amphora, Surirella, Hyalodiscus		
Blue-green algae	47	17
Oscillatoria, Merismopedia, Microcystis		
Debris	82	13
Filamentous algae	58	3
Cladophora, Enteromorpha, Vaucheria, Spirogyra, Polysiphonia		
Animal forms	26	2
Nematodes, crustacean ova		
Plant fragments	24	1
Batis maritima		

TABLE 3.—*Dietary items found in 17 stomachs of* Chanos chanos *which ranged in size from 90 to 115 millimeters standard length*

Food item	Percentage of stomachs containing the item	Percentage composition by volume
Diatoms	100	48
Navicula, Pleurosigma, Mastogloia, Nitzschia, Melosira, Coscinodiscus, Cymbella		
Debris	100	32
Plant fragments	35	10
Batis maritima		
Filamentous algae	29	7
Cladophora, Spirogyra, Polysiphonia		
Blue-green algae	35	3
Oscillatoria		
Animal forms	6	trace
Nematodes		

TABLE 4.—*Dietary items found in 59 stomachs of* Chanos chanos *which ranged in size from 116 to 402 millimeters standard length*

Food item	Percentage of stomachs containing the item	Percentage composition by volume
Diatoms	97	43
Navicula, Nitzschia, Amphora, Mastogloia, Pleurosigma, Surirella, Melosira, Cymbella		
Filamentous algae	66	20
Vaucheria, Enteromorpha, Cladophora, Spirogyra, Acrochaetium		
Plant fragments	85	14
Batis maritima		
Debris	97	11
Blue-green algae	37	3
Oscillatoria, Merismopedia		
Foraminifera	5	3
Globigerina, Spiroloculina, Bolivinita, Pulvinulina		
Nematodes	63	3
Copepods	58	3
Adults, larvae, ova		
Miscellaneous animal forms	15	trace
Polychaetes, ostracods		

Ten-pounder.—No disparity in food habits was found for fish of different sizes or for fish collected during the various seasons. The data set forth in Table 5 include, therefore, food items taken by all fish examined. It has not been ascertained as yet whether or not ten-pounders reproduce within the ponds, but frequent collection of the leptocephali within the ponds indicates that this species may be a life-long resident.

TABLE 5.—*Dietary items found in 168 stomachs of* Elops machnata *which ranged in size from 44 to 410 millimeters standard length*

Food item	Percentage of stomachs containing the item	Percentage composition by number	Percentage composition by volume
Fish:			
Mollienesia latipinna	62	57	70
Gambusia affinis	10	5	9
Crustacea:			
Leander debilis	26	14	20
Amphipoda	4	23	1
Gastropoda:			
Planaxis labiosus (shell)	trace	trace	trace

Discussion

It is apparent that Hawaiian mullet are almost entirely herbivorous, a characteristic agreeing in principle with most of the studies made elsewhere. Moreover, this species digresses from the expected size of fish-size of food ratio and telescopes the food chain because of its elaborate, pharyngeal sieving mechanism. This sieve-like apparatus apparently enables the fish to select a sufficient quantity of minute plant types and organic detritus for its sustenance. The gut contents contain only a fraction of the amount of inorganic debris that one would expect if no filter were present. The minute character of the food coupled with the small bore of the pyloric stomach probably indicate that, in order to secure adequate nutrition, feeding ensues for extensive periods.

Types of diatoms consumed are similar to those taken by Egyptian mullet. The scarcity of planktonic diatoms in Hawaiian as well as in Egyptian mullet indicates that the mullet is primarily a littora feeder on bottom-dwelling types. Since many of the diatoms are epiphytic and since epithelial plant fragments were frequently encountered, it is safe to assume that they also browse on algal plants and exposed roots of bank vegetation. Larger plant fragments are filtered out, permitting only the diatoms and other minute algae to enter the oesophagus.

Actual feeding behavior of mullet has been observed in captives in aquaria. They swim head downward, protract the premaxillary to bring the mouth opening to a horizontal position at the surface of the mud, and move the head rapidly from side to side while the surface layer of the mud is sucked in. The side to side movements of the head of juvenile mullet are so violent that the entire body vibrates. The food is sifted over in the mouth and the mud is rejected in a small cloud. In the shallow littoral area of ponds where diatoms are most abundant and where mullet are freqnently seen, the water is continually stirred up, apparenty the result of feeding activities. Young mullet frequnently feed in schools at the surface of the water and have been observed to ingest the surface scum which contains numerous diatoms. These diatoms are normally bottom-dwelling types; however, it is known that many forms will rise occasionally to the surface of the water because of reproductive activity, accumulation of fatty foodstuffs, accumulation of oxygen bubbles, or disturbed water movements.

The absolute rates of increase of intestinal length and of standard length of mullet are different, but they tend to maintain a constant ratio to each other—that is, that the relative growth of these two parts tends to be constant. No fish below 35 millimeters standard length were measured, but fish examined above this size possessed a mean intestinal length-standard length ratio of 3.2:1. The length of the mullet's intestine, though comparatively shorter than that of the milkfish, is adaped to herbivorous habits.

Although milkfish are herbivorous, their diet differs somewhat from that sustaining them in Asiatic ponds. Fish under 90 millimeters standard length consume an almost exclusive diet of minute algal types (Table 2). Asiatic pond operators culture this type of food especially for juvenile fish. A significant difference between the diet of larger fish of Hawaiian ponds and the diet of similar fish in Asiatic ponds results from the different operational procedures employed in these areas. Larger, filamentous green algae are cultivated for milkfish in Asiatic ponds. In Hawaii no such cultivation is attempted, with the result that these types are present in insufficient quantities to sustain a population of milkfish. Milkfish are facultative feeders in Hawaii (Tables 3 and 4) taking a greater amount of minute food types than they would if larger algae were available.

Heteronomous growth of the intestine of milkfish became apparent when measurements of intestinal length were plotted against standard length. No measurements were made on fish smaller than 55 millimeters standard length, but when fish attain a standard length of about 90 millimeters a marked acceleration in growth of the intestine begins and persists until the fish reach a standard length of about 115 millimeters, after which the growth rate slackens perceptibly. An intestinal length-standard length ratio between 2.3:1 and 3.8:1 obtains for fish between 55 and 90 millimeters standard length respectively. During this early period of growth a fish increases its standard length about 80 per cent, while the intestinal length undergoes an increment of approximately 100 per cent. It will be noted that the ratios mentioned above are similar to those found for mullet of all sizes. Moreover, the food items consumed by these juvenile milkfish, except for a small amount of filamentous algae and small animal forms, are similar to those taken by all mullet examined.

The intestine of milkfish between 90 and 115 millimeters standard length increases approximately 200 per cent, as compared to a contemporary increment in body length of about 25 per cent. The intestinal length-standard length ratio mounts from about 3.5:1 for fish of 90 millimeters standard length to approximately 7.2:1 for fish which have attained a standard length of 115 millimeters.

Intestinal growth, relative to increase in standard length, is retarded in fish above 115 millimeters. For example, the longest fish measured (272 millimeters standard length) showed an increment in length of 137 per cent from the 115 millimeter size, whereas the intestinal length increased only 88 per cent and the ratio of intestinal length to standard length diminished to approximately 6.5:1.

Rapid acceleration of intestinal growth and the maintenance thereafter of an increased intestinal length relative to body length may be a direct result of the digestive requirements associated with an increased mass of larger plant foods eaten by fish above 90 millimeters standard length. Evidence favoring this hypothesis is found in the substantial increase in consumption of filamentous algae and plant

fragments which comprise but 4 per cent of the total food eaten in fish below 90 millimeters standard length (Table 2). During the period of marked acceleration in intestinal length larger food items, which compose about 17 per cent of the total food consumed, partially displace from the diet such minute foods as diatoms and blue-green algae (Table 3). After the intestine attains its maximum length relative to body length larger plant foods make up approximately one-third of the total food bulk (Table 4).

The feeding habits of milkfish are similar to those described above for mullet. The diatoms present in the gut indicate that food is often sucked from the littoral bottoms of the ponds. Without a filtering device present to segregate material taken into the pharyngeal cavity, larger food types pass into the oesophagus along with diatoms and blue-green algae. Many plant fragments which are apparently derived from the epithelial tissue of roots of *Batis maritima* are found in the stomachs. This plant grows abundantly along the edges of the ponds and its roots extend into the pond water. Many epiphytic algae growing on these roots are taken by browsing fish. The large proportion of diatoms consumed by milkfish shows that this species competes with mullet for the existing food supply, a fact which cannot be overlooked in appraising pond fish production. Herre and Mendoza (1929) claim that mullet offer no competition to milkfish in ponds in the Philippines. This condition is to be expected where larger, cultivated, algal types are accessible.

Increased production of minute algal types and a decrease in predators seem to be the only practical methods of approach toward increasing the yield of mullet and milkfish in Hawaiian ponds. Predator relationships may best be evaluated when further studies are made. There is no doubt that diatoms and other minute algae can be increased by the application of inorganic fertilizers. Experimental application of inorganic fertilizers to fresh-water ponds by Smith and Swingle (1939) and to salt water lochs by Gross, *et al.* (1944) show that the phytoplankton is greatly increased. Although these investigators fail to mention bottom-dwelling algal types, we may assume that the increase of these types was commensurate with the phytoplankton. Plant growth in most Hawaiian ponds is restricted to shallow water along the edges of the pond. Shallow areas not over one or two feet in depth out in the ponds also contain a substantial amount of algae. Penetration of sunlight seems to be the limiting factor in this case because the turbidity of pond water is high most of the day. Although inorganic fertilizers probably would substantially increase the food supply of mullet and milkfish in the present ponds, it seems evident that the construction of more shallow water areas within the ponds would materially augment foraging possibilities. Lessening the competition between mullet and milkfish could be accomplished only by manipulating water levels to cultivate larger algal types. Hawaiian ponds are not constructed for this purpose.

The presence of the ten-pounder in Hawaiian ponds is considered undesirable. Although these data do not show that mullet and milkfish compose part of this predator's diet, it cannot be assumed that the young of these desirable species are not consumed on occasion. Mosquito fish and shrimps occur in prodigious quantities in virtually all Hawaiian ponds. The ease with which ten-pounders may catch these more sluggish forms may be responsible for the apparent disregard of the faster moving juvenile mullet and milkfish.

Feeding habits of ten-pounders below 270 millimeters standard length seem to follow the expected size of predator-size of prey ratio. Very small fish take very small shrimps, amphipods, and juvenile mosquito fish; larger fish catch prey of greater size. The carnivorous habits of the ten-pounder are manifested by the mean intestinal length-standard length ratio, which, for fish ranging from 44 to 410 millimeters standard length, is 1:2.4. The ratio changes little for fish throughout this size range.

Ten-pounders are known to reach sizes somewhat larger than those analyzed for this study. In the case of predators the size of food is the main factor underlying the existence of food chains; therefore, it is reasonable to expect these large ten-pounders to consume larger prey when the opportunity arises. Many of the fish examined were of sufficient size to have captured much larger prey than was found in their alimentary tracts. It seems likely, therefore, that the ratio of size of predator to the size of prey may be modified because of the myriad of mosquito fish and shrimps available. If this hypothesis were true, and the facts seem convincing, the damage to pond fisheries by ten-pounders may be considerably less than is commonly believed. Inasmuch as this fish is desirable for the market and appears to sustain itself on food not utilized by the other leading market fish, it may prove an asset to pond operators.

Summary

1. This study was undertaken to secure information about food-chains and the food cycle in Hawaiian fish ponds, in order to ascertain which links in the food-chains might be altered to increase the yield of market fish.

2. Analyses of 212 stomachs of mullet of various sizes show that they subsist largely on littoral diatoms and blue-green algae. The diet does not differ with the season or with the size of the fish. Mullet have succeeded in telescoping the food chain to which they belong, and are able to obtain nutriment from plant types at the base of the food pyramid because of the presence of a unique pharyngeal sieving device. The intestine, similar to that of other herbivores, is long; but it is comparatively shorter than that of the milkfish.

3. In addition to sucking in littoral, bottom-dwelling diatoms and other algae, mullet frequently browse on larger algae to secure minute epiphytic forms. The size of the cardiac pouch and bore of the pyloric

portion of the stomach indicate that mullet probably feed for lengthy periods.

4. Milkfish are herbivorous and show no seasonal variation in foods taken. Juvenile milkfish subsist almost entirely on minute algal types, while larger fish, although nearly half of the diet is diatomaceous, take a greater proportion of larger algae. The intestine is comparatively longer than that of the mullet, and a marked acceleration in intestinal growth occurs when the fish reach a size between 90 and 115 millimeters standard length. This rapid elongation of the intestine is reflected in the transition in food predilections from minute to larger plant types which become increasingly important in the diet.

5. Competition for food between mullet and milkfish is greater than hitherto supposed and cannot be lessened with present operational methods.

6. Algal foods preferred by mullet and milkfish can undoubtedly be increased in quantity by the application of inorganic fertilizers. High turbidity restricts rich plant growth to shallow littoral areas; increased shallow areas within the ponds would greatly augment the available food.

7. The diet of the ten-pounder, a carnivorous fish, consists mostly of mosquito fish and shrimps. These food types occur in prodigious quantities in most ponds, are easy to catch, and are probably responsible for the lack of predation on faster moving juvenile mullet and milkfish. The food of small to medium-sized ten-pounders follows the expected size of predator-size of prey ratio, and it is probable that this ratio is modified in the case of larger fish because of the myriad of mosquito fish and shrimps available. The intestine is a short, straight, carnivorous type.

8. Ten-pounders apparently damage pond fisheries less than is commonly believed; in fact, they may prove an asset to the industry.

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FOOD-CHAINS AND THE FOOD CYCLE IN HAWAIIAN FISH PONDS.—PART II. BIOTIC INTERACTION[1]

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ABSTRACT

The food and feeding habits of the influent and subinfluent species (11 fish, 4 shrimps, and 4 crabs) in Hawaiian fish ponds were analyzed to ascertain the biotic interaction. The dominant species were treated in a similar way and reported upon earlier. The ponds are virtually autarchic, and the available food supply is almost totally dependent upon the physical features of the biotope. Microbenthos and detritus were found to support most of the herbivorous species while larger benthos, emergent halophytes, and plankton play minor roles. The animal assemblage within the ponds includes not only herbivores and omnivores but is replete with carnivores, several of which are voracious and reach a large size.

Interspecific competition for food and existence is severe. Both mullet and milkfish subsist on microbenthos. Competing also for this source of food are prodigious numbers of poecilids (*Mollienesia latipinna* and *Gambusia affinis*) and shrimps which, in turn, form the strongest links in the food-chains between plants and predators. Large carnivores prey upon economically valuable herbivores and also prey upon worthless carnivores.

The results of the law of diminishing returns to the pond operators in weight of fish, and therefore in revenue, are operative and seem inevitable if current practices remain unchanged. Since the greatest harvest is to be secured from the marketable herbivores, it follows that rough herbivores and all predators should be eliminated, and every means available should be employed to augment the existing supply of benthos.

INTRODUCTION

The present paper, the second and concluding one concerning biotic interaction in Hawaiian fish ponds, comprises an account of the general ecological features of the pond community, treats the food and feeding habits of the pond constituents with the exception of the three dominant species which were subjects for the first paper (Hiatt, 1947), and includes a discussion of those elements within the biota which might be changed to increase the yield of Hawaiian fish ponds. Since the inhabitants of this pond community form a closely interdigitated, mutually dependent unit, a biocoenological approach is the most attractive and seems likely to illustrate most satisfactorily the biotic interaction. The basic aim of this study is to understand the laws that govern the dynamics of this biocoenosis and its quantitative and qualitative content. With such information at hand it should be possible to produce the alterations in the composition of the community which we find desirable in connection with the increased production of marketable fish. It must be borne in mind that two types of

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research are of vital importance in community studies: the study of the biotic potential and the degree of mortality in all stages of development, and the quantitative and qualitative study of the feeding of the organisms. The Hawaiian pond community differs slightly from natural pond communities generally studied because two of the dominant constituents are generally placed in the pond in numbers which would far exceed natural reproduction. Moreover, the number of fry placed in the ponds is considerably greater than the ponds could possibly sustain as adults. Consequently, biotic potential and mortality are largely obviated and are definitely subordinated in importance to biotic interaction. The present study, therefore, provides by far the most important segment of the information required to manage the ponds on the most efficient basis.

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Description of the Ponds

The Hawaiian Archipelago is the scene of the greatest development of fish ponds of the type which seems best described by the term "primitive." These ponds for marine fish were made by walling up the narrow entrance to a bay or inlet or by walling in a suitable section of flat reef. An opening was left so that fish borne by the incoming tide could freely enter, after which it was closed by a gate which prevented their exit but allowed the interchange of water. Manifestly there was little control over the stocking of ponds by this method, and chance ruled the results obtained. This chance stocking was later superseded by seining up the mullet and milkfish fry along the shores of the reef and placing them in the ponds. The screened gates under this system permitted the interchange of water, but prevented fish from entering or leaving the ponds at all times. At present, the same practice is followed by the more enterprising operators. Some of the ponds, however, still function in the most primitive manner. Thus most of the ponds have become practically autarchic communities with an assemblage of constituent species which fluctuate only with the introduction of mullet and milkfish fry and the seining out of the larger fish by means of gill nets.

Fish ponds in other areas (East Indies, Malaysia, and the Philippine Islands) have undergone a gradual evolution in form of construction and operation until the fry are put into specially constructed ponds in place of those more or less naturally suited for the purpose. In these ponds, the algae consumed by milkfish and mullet are carefully cultured, and the "pastures" are rotated, which permits periodic draining of diked-off sections, removal of predators and herbi-

vorous competitors, and sun-baking of the bottom mud which seems to encourage the growth of algae when subsequently inundated.

This type of well-organized pond, described by Herre and Mendoza (1929), may be termed "modern." Since 1920 the development in the Philippine Islands of these modern ponds has been greatly accelerated. No such transition from ancient practice has occurred in Hawaii. It is doubtful whether many modern ponds will ever be constructed in Hawaii because of: (1) the lack of suitable areas, (2) high cost of labor required for their construction, and (3) the high financial value assessed to such land, making rental rates prohibitive. Some features of Hawaii are favorable to the pond fish industry. Aside from slow silting in, the ponds are located in a region of optimum physical environment. Many of those limitations which the vicissitudes of nature of less-favored regions place upon their fauna are absent.

The salinity alone varies greatly, both in different localities within the ponds, and seasonally. Since the important marketable fish and the biotic constituents essential to them are euryhaline, the fluctuating salinity appears to result in no adverse effect on the community.

Food Supply

The animal life present in an area is dependent primarily upon the amount of food available in the biotope in question. Although most ponds are open to the sea through screened gates at high tide, comparatively little biotic interchange occurs. The amount of plankton entering the ponds is probably offset by the amount of plankton leaving during the receding tide. Moreover, the plankton is not a significant source of nutriment to the fish pond fauna (see section on plankton). Therefore, the amount of animal life in the ponds will depend upon the amount of vegetation in the association, which in turn depends directly on the biotope. The full use of food materials prepared by the plants is contingent upon the structural adaptations of the animal species present, which enable them to utilize certain plant types. The mullet (*Mugil cephalus*) exemplifies such a phenomenon (Hiatt, 1947).

Generally speaking, the basic food supply of the animal constituents is of five main types, as follows:

1. *Microbenthos.*—This is a complex found abundantly as a crust or mat upon the bottom of the ponds and is similar to "lab-lab" found upon the floor of nursery ponds for milkfish (*Chanos chanos*) in the Philippines (Herre and Mendoza, 1929). It forms an almost solid mat on the bottom of the ponds from the edges down to a depth of approximately two feet. As greater depths are reached it becomes sparse, probably because of diminished light penetration as a result of nearly constant wind disturbances which fill the water with suspended detritus.

A microscopic examination of this complex shows it to be com-

posed largely of unicellular, colonial, and filamentous blue-green algae, mostly small species of Oscillatoriaceae; there is a great variety of diatoms, bacteria, unicellular green algae, and a small proportion of very fine threads of Chlorophyceae, predominantly *Cladophora* spp. and *Vaucheria* sp. It also contains many protozoans, nematodes, and small crustaceans. The incoming tide and wind disturbance will often break up large patches of benthos filled with oxygen which buoys them up to the surface. Countless numbers of sail-fins (*Mollienesia latipinna*) are often seen eating the floating benthos.

This food source is by far the most important within the biocoenosis. Both mullet and milkfish subsist largely on this microbiota.

2. *Larger benthonic plants.* These consist mainly of algae, although in certain areas of ponds which are slightly brackish or fresh the phanerogam, *Halophila ovalis,* is present. In general, the larger algae are not abundant in the fish ponds, but considerable variability occurs in this regard. *Cladophora, Enteromorpha, Vaucheria,* and *Ulva* are most commonly found.

Although several ponds contain extensive pastures composed of larger algal species, relatively few animals browse them while the algae are still alive. Adult milkfish will consume considerable amounts of these algae as has been shown in other areas (Maxwell, 1921; Herre and Mendoza, 1929) and in Hawaii (Hiatt, 1947). Cultural procedures employed in Malaysia and in the Philippines for rearing the larger benthonic algal species were noted in my previous paper.

3. *Emergent halophytes.*—The halophyte, *Batis maritima,* grows around the edges of most Hawaiian ponds. At high tide the numerous roots and stems which extend out into the pond are submerged and provide some food to several pond inhabitants. For the most part the epidermal layers are grazed or scraped off by both fish and crustaceans. No species feeds exclusively on this plant, but a considerable proportion of the food consumed by adult milkfish comes from this source. Many species of epiphytic algae consumed by herbivorous constituents grow on the submerged portions of this plant.

4. *Plankton.*—Substantial quantities of plankton are formed in the ponds. The primary constituents of the plankton are larval and adult calanoid copepods, larval shrimps and crabs, and a few planktonic diatoms. The constant stirring of the benthos by wind and waves fills the water with suspended benthonic microbiota and detritus.

Few constituents of the fish pond community consume plankton. Barnacles along the edges of the pond walls and an anchovy (*Anchoviella purpurea*), which swims into the ponds through the screened gates, subsist on this food source exclusively.

5. *Detritus.* The particulate matter, or detritus, which is formed by the disintegration of plants and animals, is of great importance as a source of food in all ponds. Intermixed with detritus are, of course, vast quantities of micro-organisms belonging to the microbenthos. It is, therefore, impossible for animals which feed on the bottom surface

layer to segregate living types of food from detritus. Consequently, these animals always contain both detritus and benthos in their alimentary tracts.

Larger benthonic plants and plankton seem to be of slight significance to the Hawaiian fish pond community. However, if the biotope would support larger benthos in greater quantities, milkfish would gain a far more adequate source of food than is available to them at present. *Batis maritima*, which is used as a source of food and as a substrate for valuable epiphytic algal species, is of considerable importance. Microbenthos and detritus are unquestionably the dominant sources of nutriment, with the former in the ranking position.

MacGinitie (1935) found that in a slough environment the plankton constituted a very insignificant link in the food-chains of the mud-living animals. In such an envirenment, where bacterial action is enhanced by relatively high temperatures and by the nearly enclosed nature of the habitat, he found that detritus formed by far the greater portion of the basic food supply. According to the investigations of Blegvad in Danish coastal waters (*cit.* Shelford, 1929, p. 114), the living plankton is not significant as a food for bottom-living forms of the sea. He maintained that detritus formed the principal food of nearly all the invertebrates of the sea bottom. Hewatt (1937) emphasized the fact that although detritus, formed principally from the larger benthonic algae along the central California coast, was significant as a source of food to other organisms, it in no way subordinated living microplankton.

Obviously all areas differ with respect to the basic source of food. The small quantity of large benthonic algae in Hawaiian ponds precludes the formation of great quantities of detritus. The presence of the extensive mat of microbenthos supplements the amount of detritus present to form a direct source of nourishment of profound importance to the higher animals.

Ecological Classification of Animal Constituents

Since fish ponds vary with regard to their state of preservation and upkeep, the animal assemblage within them fluctuates. Several ponds are in an excellent state of repair with tight walls and gates. However, not all of these well-constructed ponds are operated with maximum efficiency. Other ponds have ill-fitted gates or crumbled walls. Such run-down ponds generally contain the same species as the better ponds, but quantitative differences occur. For example, the greatest mass of fish found in well-constructed, carefully regulated ponds generally consists of mullet or milkfish or both. In ponds which are not well regulated or are not adequately kept in repair, the greatest mass of fish may be and often is composed of poecilids (chiefly *M. latipinna*).

Notwithstanding the variation noted above, it seemed convenient to group the pond fauna into three of the categories generally recognized

by marine ecologists. The following classification is based on the occurrence of species in a well managed pond kept in good repair. In order to circumvent any misunderstanding concerning these categories, each is defined below, and the characteristic species of each group are listed.

Dominants.—These are animals of outstanding abundance or conspicuous influence in the community: Mullet (*Mugil cephalus*); Tenpounder (*Elops machnata*); and Milkfish (*Chanos chanos*).

Influents.—These are common animals which are usually effective in modifying the well-being or numbers of the dominant group or of other influents without changing the essential structure of the community; their roles are generally shown in ponds as benefactors, competitors, or predators:

Sail-fin (*Mollienesia latipinna*)
Barracuda (*Sphyraena barracuda*)
Bonefish (*Albula vulpes*)
Lizard fish (*Saurida gracilis*)
Sleeper (*Eliotris fuscus*)
Shrimp (*Leander debilis*)

Subinfluents.—These animals affect the life of the community, but to a lesser extent than do the influents:

Anchovy (*Anchoviella purpurea*)
Goby (*Gnatholepis anjerensis*)
Goby (*Gobiichthys papuensis*)
Mosquito fish (*Gambusia affinis*)
Puffer (*Tetradon hispidis*)
Papio (*Caranx sexfasciatus*)
Shrimp (*Leander pacificus*)
Shrimp (*Bithynis grandimanus*)
Snapping shrimp (*Crangon crassimanus*)
Samoan crab (*Scylla serrata*)
Hawaiian crab (*Portunus sanguinolentus*)
Red crab (*Podophthalmus vigil*)
Mud crab (*Panopeus pacifica*)
Polychaetes

Methods

Stomachs analyzed in this study were taken from animals collected throughout the year in several ponds on the islands of Oahu and Molokai in the Territory of Hawaii. Small fish and invertebrates were immediately preserved in a 15 or 20 per cent solution of formalin. The digestive tracts of larger fish were removed and preserved in separate cloth bags or containers. The stomach contents of fish which consumed microscopic food items were placed in a small vial of preservative and shaken to break up food masses and to form an even suspension in the preservative. Several drops of the suspension were immediately drawn into a pipette and transferred to a glass slide and examined microscopically. Where results could be expressed numerically the figures given indicate the percentage of the total number of all items counted. In other cases the results are expressed in terms of relative composition by volume. In all cases the incidence of occurrence of items among fish or invertebrates examined is expressed as the percentage of the total number of specimens analyzed. In order to arrive at the summaries shown for *Saurida gracilis, Eliotris fuscus,*

and *Sphyraena barracuda*, each stomach was weighted according to the amount of food it contained following the method set forth previously (Hiatt, 1947).

Results

INFLUENTS

Albula vulpes.—The bonefish, or "'o'io," is a common fish, highly valued from the Oriental's viewpoint. It is eaten raw because of its soft bones or prepared as fish cakes. Table 1 summarizes the food items consumed by this species.

TABLE 1.—*Dietary items found in 22 stomachs of* Albula vulpes *which ranged in size from 182 to 340 millimeters standard length*

Food item	Percentage of stomachs containing the item	Percentage composition by number
Crustacea:		
Podophthalmus vigil	27	many fragments
Crangon crassimanus	23	5
Panopeus pacificus	9	5
Portunus sanguinolentus	5	few fragments
Leander debilis	5	1
Corophium sp.	5	1
Annelids:		
Nereis sp.	68	77
Insects:		
Arctocorixa blackburni	32	10
Fish:		
Mollienesia latipinna	5	1
Plant fragments	5	few fragments

Sphyraena barracuda.—Barracuda, or "kaku," are present in all ponds. Juvenile barracuda probably enter through the screened gates or at times when the pond workmen may carelessly leave the gates up. Pond operators believe the barracuda to be the most destructive fish in the fish ponds, where they grow to a very large size. Barracuda habitually appear half asleep and float in one position close to the surface, often making slow movements from side to side. When they are disturbed they move with extreme rapidity.

Cuvier and Valenciennes (1829; *cit.* Gudger, 1918, p. 80) mentioned a spet (barracuda) of the "middle sea" having its stomach filled with atherinas and little clupeids. Bullen (1904, *cit.* Gudger, *loc. cit.*) dissected a number of barracuda from the Indian Ocean and found their stomachs filled with small mackerel. This investigator also reported that young salmon going to the sea for the first time after being planted in New Zealand were consumed by barracuda. Linton (1910) found no food other than fish in ten specimens of *S. barracuda* collected at the Dry Tortugas. Gudger (*op. cit.*) found the barracuda to be strictly piscivorous, taking all available species indiscriminately. He also noted that they often herd their prey.

Infrequent catches, coupled with the local practice of selling these fish "round,"[2] made it difficult to secure stomachs of large fish for

[2] "Round" refers to the local practice of selling whole, uneviscerated fish at the fish markets.

examination. The larger forms undoubtedly consume other pond fish of commercial importance. Steven (1930) and Elton (1939) have shown that in carnivores there is an optimum size of food which is the one usually eaten. If this be true, it would be axiomatic that as barracuda increased in size they would consume prey of increased size. However, several of the barracuda examined were of sufficient size to have captured much larger prey than was found in their alimentary tracts. It seems likely, therefore, that the ratio of size of predator to the size of prey may be modified as it is in the ten-pounders because of the presence of a myriad of sail-fins, mosquito fish, and shrimps available (Hiatt, 1947). Stomach analyses for this species are set forth in Table 2.

TABLE 2.—*Dietary items found in 15 stomachs of* Sphyraena barracuda *which ranged in size from 46 to 638 millimeters standard length*

Food item	Percentage of stomachs containing the item	Percentage composition by number	Percentage composition by volume
Fish:			
Gnatholepis anjerensis	27	22	34
Mollienesia latipinna	20	22	23
Shrimps:			
Leander debilis	53	56	43

Mollienesia latipinna.—Next to the dominants the sail-fins, American poecilids native to the coastal region of the southern United States, occur in greatest abundance. Van Dine (1907) stated that this poecilid has resided in Hawaii since 1905, at which time the Hawaiian government commissioned Alvin Seale to obtain fish feeding on mosquito larvae in the United States and to transport them to Hawaii. These fish were to be used in the anti-malarial campaign then in progress in the Hawaiian Islands. At Seabrook, Texas, he obtained a quantity of *Gambusia affinis* and some specimens of *M. latipinna.* An examination of several stomachs of these species by Seale (*cit.* Van Dine, *op. cit.*, p. 6) showed them to subsist largely on larvae of various insects, including those of mosquitoes. He noted that the food habits of the two species differed slightly but failed to state the differences. These poecilids were transported to Hawaii and placed in fish ponds, streams, and irrigation ditches. They multiplied rapidly and *G. affinis* was found to be especially efficacious in devouring mosquito larvae, but *M. latipinna* was of no practical utility for this purpose.

Herre and Mendoza (1929) found that *M. latipinna* feeds largely on the algal complex that covers the bottom of nursery ponds in the Philippines. This layer, known as "cream of the mud" and called "lab-lab" by the Tagalogs, is composed of a mat of blue-green algae with which are mingled diatoms, desmids, some fine filamentous green algae, and quantities of protozoans and other microscopic animals. They also consume to a limited extent the common filamentous green algae, or "lamut," of the fish ponds. These fish multiplied

to such an abundance in Philippine ponds that they became a serious detriment to the success of the ponds. This was especially true in the nursery ponds, since sail-fins there devour the "lab-lab" upon which milkfish fry subsist.

From the above account it appears that these fish are apparently as abundant in some Philippine fish ponds as they are in most Hawaiian ponds. They are euryhaline and occur in ponds or areas of ponds with high salinity as well as in brackish sections. Vast numbers can be taken up by a single dip net. Temporary eradication of the sail-fins in Philippine ponds is achieved by draining, cleaning, and drying the ponds. No simple solution presents itself for Hawaiian ponds, most of which could not be drained completely.

Food items composing the diet of this species are shown in Table 3.

TABLE 3.—*Dietary items found in 27 stomachs of* Mollienesia latipinna *which ranged in size from 50 to 65 millimeters standard length*

Food item	Percentage of stomachs containing the item	Estimated percentage composition by volume
Microbenthos	100	60
Detritus	100	35
Plant fragments	4	5

Saurida gracilis.—The lizard fish, or "ulae," is common on sandy or muddy shores at shallow to moderate depths. Economically worthless, they are important in the pond community because of their abundance and significant position in the food cycle. Table 4 indicates the food predilections of this carnivorous species.

TABLE 4.—*Dietary items found in 50 stomachs of* Saurida gracilis *which ranged in size from 100 to 180 millimeters standard length*

Food item	Percentage of stomachs containing the item	Percentage composition by number	Percentage composition by volume
Crustacea:			
Leander debilis	50	61	57
Leander pacificus	2	2	2
Fish:			
Mollienesia latipinna	24	22	30
Gambusia affinis	6	9	5
Anchoviella purpurea	2	4	4
Albula vulpes (leptocephalus)	2	2	2

Eliotris fusca.—Sleepers, or "oopu akupa," are common on muddy bottoms at shallow depths in fresh, brackish, and salt water throughout the Hawaiian Islands. They form a rather inconspicuous part of the pond community because of their dirty brownish color and habit of resting on the substrate, but they are an important influent by virtue of their abundance and feeding habits. Table 5 summarizes the dietary items taken by this species.

Leander debilis.—Vast numbers of this shrimp occur in the ponds and it shares with *M. latipinna* coimportance as the most significant link between the plant complex and the carnivores. An examination

TABLE 5.—*Dietary items found in 22 stomachs of* Eliotris fusca *which ranged in size from 90 to 170 millimeters standard length*

Food item	Percentage of stomachs containing the item	Percentage composition by number	Percentage composition by volume
Crustacea:			
Leander debilis	32	5	30
Panopeus pacificus	23	3	14
Leptochelia dubia	9	23	9
Leander pacificus	9	1	7
Gammarus sp. and *Corophium* sp.	9	11	4
Ova	5	39	3
Fish:			
Mollienesia latipinna	18	2	9
Anchoviella purpurea	5	....	6
Saurida gracilis	5	1	1
Insects:			
Arctocorixa blackburni	5	2	1
Plants:			
Diatoms	9	many	6
Filamentous algae	5	few	3
Plant fragments	14	13	7

of the stomachs of several shrimps shows their diet to be composed of the thin mat of microbenthos and detritus. Apparently they do not comb their food from the water but ingest it with sifted mud. All of the stomachs contained numerous diatoms, protozoa, and detritus.

SUBINFLUENTS

Anchoviella purpurea.—The anchovy, or "nehu," frequents protected bays and harbors where the water is calm and swims in large schools near the surface. The small size of this species (maximum standard length about 50 millimeters) enables it to enter through the screens separating the ponds from open water. At no time are "nehu" present in the ponds in great numbers, but they form one of the few links between the zooplankton and the larger carnivores. Territorial law restricts the taking of "nehu" except for baitfish.

Copepods, chiefly calanoids and their ova, constitute 94 per cent of the total food consumed and were present in 90 per cent of the stomachs examined. Crab zoeae were found in 85 per cent of the stomachs but comprised only 4 per cent of the total number of food items. Other constituents of lesser importance are nauplii and cypris larvae of barnacles, zoeae and megalopa of *Leander debilis,* and the sergestid, *Lucifer* sp.

Gobiichthys papuensis.—This goby, or "paoo kaulaloa," one of two commonly found in the ponds, is a euryhaline species and attains a standard length of about 110 millimeters. Contrary to the carnivorous feeding habits of most gobies, an examination of several stomachs shows this species to subsist mainly on microbenthos and detritus. Diatoms and detritus were exceedingly abundant in all stomachs. Other components of the benthos found were larval and adult copepods, nematodes, and a small amount of filamentous algae.

Gnatholepis anjerensis.—This goby, or "oopu," is a small species not exceeding 60 to 80 millimeters standard length. It frequents mud

flats in both salt and brackish water and is commonly found in the ponds. An omnivorous species, its diet is varied with detritus and microbenthos found in most stomachs. One stomach contained two small, crushed barnacles. Others contained crab fragments, shrimps, nematodes, and the sexual form of the ant, *Pheidole megacephala.*

Gambusia affinis.—This mosquito fish inhabits the fresh or brackish areas of ponds and is seldom seen in the more haline sections. Large schools are observed swimming at the surface or in among the roots of *Batis maritima.* Most of the literature pertaining to *Gambusia* concerns its use in relation to mosquito control, and Self (1940) adequately summarizes the literature from this standpoint. All investigators concur that these fish subsist on living material, especially mosquito larvae when they are present. Fermi (*cit.* Self, 1940, p. 395) suggests that they are selective in feeding habits, take only species with a soft integument, and spare the larvivorous notonectids, maucorids, larvae of *Hydrophilus, Dytiscus, Gammarus,* and others which feed on anophelines.

The present analyses of many stomachs from fish which ranged from 20 to 35 millimeters standard length show the species to be omnivorous and not particularly selective. The ponds, however, do not support an appreciable number of insects having aquatic larvae. This fact may account for the great differences found between the food habits of *Gambusia* in Hawaiian fish ponds as compared with fresh-water ponds.

Nearly half of the stomachs examined contained diatoms (*Pleurosigma, Navicula, Amphora,* and *Cymbella*). Over one-third contained plant fragments, and about one-fifth of them had a substantial amount of detritus. Among the animal food taken, water-boatmen (*Arctocorixa blackburni*) led the list and were present in one-third of the stomachs. Other animal types taken in lesser frequencies were calanoid copepods, nematodes, fragments of some dipterous insect, chironomid adults, amphipods (*Gammarus* sp.), thrips (Thysanoptera), ants, and some skeletal fragments and scales of *Gambusia affinis* itself.

Tetradon hispidis.—The puffer, or "'o'opuhue," is common in most Hawaiian ponds, and in some, particularly on the island of Molokai, is abundant. It is one of the common fish in shallow bays and estuaries throughout the islands. Its flesh is generally regarded as poisonous, and a Territorial Board of Health regulation prohibits its sale. Since it is primarily a carnivore, its influence in the ponds is considerable.

The several stomachs examined from fish which ranged from 120 to 300 millimeters standard length showed that they take shrimps, crabs, gastropods, and amphipods. One stomach contained a large amount of a common colonial diatom (not yet identified). Apparently little selection of food occurs and items are taken commensurate with their availability.

Caranx sexfasciatus.—The black "ulua," called "papio" when young, is a constantly moving fish which often enters fish ponds if the

gates are left open. In open water along the shores of the islands this species grows to a large size and is one of the most important market fish. Although this carangid is seldom found in abundance in most ponds, its roving movement and carnivorous feeding habits influence the community to some extent.

Stomach analyses of "papio" which ranged from 210 to 360 millimeters standard length taken from ponds show that its diet consists mainly of crustaceans, with shrimps (*Leander debilis*) constituting about 70 per cent of the total volume of food consumed. Other species taken in lesser quantities are snapping shrimps (*Crangon crassimanus*) and swimming crabs (*Thalamita integra, Portunus sanguinolentus,* and *Podophthalmus vigil*). No fish were found in pond-taken "papio" but they are known to consume eels and other fish along the shore.

Leander pacificus.—This shrimp, less common but larger than *L. debilis,* is nowhere as abundant as the latter. However, it occurs in considerable quantities and is found in the stomachs of many of the omnivorous and carnivorous pond constituents.

Its food consists principally of detritus and microbenthos. Some fragments of larval crustaceans were also found, but these were probably part of the detritus or were present as a result of scavenging activity.

Bithynis grandimanus.—Quantities of this large, brackish water shrimp are often taken in shrimp traps set in the ponds at night. The species is rarely taken during diurnal hours.

An omnivorous feeder and scavenger, it was found to consume a considerable amount of detritus and diatoms. Many fragments of crustaceans, sail-fins, and foraminiferans were present in the stomachs. One stomach contained several polychaete larvae.

Crangon crassimanus.—Snapping shrimps were found frequently in stomachs of several of the pond constituents. These shrimps are abundant around the edges of the ponds where they reside in small excavations in the mud.

For the most part this species is herbivorous but some had taken fragments of crustacean larvae and can be considered facultative scavengers. *Vaucheria dichotoma* composed the greatest mass of food eaten by all individuals examined. Several had eaten the epidermis from roots of *B. maritima.* The *Batis* fragments were cut into small bits and not scraped. Other items included filamentous green algae, detritus, diatoms, fragments of a foraminiferan (*Pinnularia*), and fragments of larval crustaceans.

Scylla serrata.—The Samoan crab is the largest swimming crab about the Hawaiian shores. It was imported from Samoa and Fiji shortly after the turn of the century to provide a large edible crab for the local market. It has become very successfully established, especially on Oahu and Molokai where it thrives in estuaries, mouths of rivers, shallow bays, and fish ponds. Considerable revenue is obtained by

pond operators who trap the crabs and sell them in the Honolulu fish market. It is by far the leading commercial crab of the Hawaiian Islands. Its burrowing habits cause some concern to pond operators because it often burrows through the dikes. These burrows gradually widen as the water runs through them, and if they are not repaired quickly, serious damage may result.

A strictly carnivorous species, this crab is often observed clinging to the screened gates of fish ponds where the currents coming in and going out attract fish in large numbers. Stomachs of crabs taken in ponds have failed to show evidence of their piscivorous habits, but instead contain large numbers of fragmented remains of the shrimp, *L. debilis*. Captive crabs in aquaria containing fish and eels have been observed to catch their prey and tear off large pieces of flesh with their extremely sharp-pointed chelae.

Portunus sanguinolentus.—The Hawaiian crab is the largest of several species of *Portunus* about Hawaiian shores. Large numbers, many of which are taken from fish ponds, are sold in the Honolulu fish markets.

This species is strictly carnivorous. Food items found in several stomachs in order of their relative composition by number are shrimps (*L. debilis*), crab fragments, polychaete fragments, and fragments of *M. latipinna*.

Podophthalmus vigil.—The red crab is one of the largest swimming crabs native to Hawaii. This species is of considerable economic importance and is used extensively for food. Large numbers are sold in the Honolulu fish markets. It thrives in shallow bays, mouths of rivers, and estuaries where the substrate is sandy or muddy. The extraordinary long eyestalks enable this species to bury itself almost completely in the substrate, leaving only the tips of the eyestalks exposed.

The omnivorous feeding habits of this crab are reflected in the fact that over 80 per cent of the stomachs contained diatoms and detritus, while 50 per cent contained fragments of the shrimp, *L. debilis*. Nearly half of them had consumed plant fragments in considerable volume.

Panopeus pacificus.—The mud crab occurs abundantly on the bottoms of most fish ponds. Its importance as a pond subinfluent lies not in its own food habits, but in its being a source of nutriment to a large number of the other animal species.

The mud crab is a scavenger as well as a feeder on detritus and microbenthos. Its food comprises plant fragments, detritus, diatoms, filamentous green algae, filaments of blue-green algae, foraminiferans, chironomid larval fragments, and polychaete fragments.

Polychaeta.—Several species of polychaetes occur in the pond, principally in tubes or in the mud of the substrate. They are *Marphysa sanguinea, Nainereis laevigata, Polydora ciliata, Audouinia semi-cinctus, Potamilla elongata,* and a fresh and brackish water nereid (*Ne-*

reis sp.) as yet *unidentified.* An account of the first five is set forth by Abbott (1945).

These polychaetes are principally scavengers and feeders on detritus. Several constituents of the pond community regularly consume these worms.

Discussion

The biotic interaction in Hawaiian fish ponds may be best understood by referring to Figure 1. Closely allied species with similar food habits are placed together to simplify the diagram.

Interspecific competition for nutriment is widespread within the pond assemblage. Mullet and milkfish, the most important marketable species, depend almost exclusively upon the benthonic microbiota for sustenance. It was pointed out previously that adult milkfish would consume greater quantities of larger, filamentous green algae (*Enteromorpha, Vaucheria,* and *Cladophora*) if such were available in adequate amounts in Hawaiian fish ponds. As the ponds are now arranged, considerable competition exists between these two desirable species. The ubiquitous *M. latipinna,* because of its identical feeding habits and great numbers, provides the most competition to the desirable market fish. No commercial value is assessed to sail-fins; consequently, they are strictly a detriment. The only possible beneficial aspect of their presence is that they may replace many juvenile mullet and milkfish in the diet of larger carnivores. On the other hand, these carnivores are doubtless a decided liability to pond operators. It would seem, therefore, that eradication of sail-fins is desirable.

Methods of removing sail-fins from fish ponds are difficult to conceive. Mention was made above of draining and drying Philippine ponds to effect their removal. Hawaiian ponds cannot be successfully drained, and such a practice would prove uneconomical because of the lack of diked-off sections to preserve desirable fish during the operation. Perhaps the only method available, aside from killing all the fish in a pond, is to drag the ponds periodically with a fine-meshed net. It may be possible to reduce the sail-fin population to a point where competition would be tolerable.

The shrimp, *L. debilis,* provides considerable competition to both mullet and milkfish because of its feeding habits and huge numbers. Like sail-fins and mosquite fish it forms a strong link between the plant and carvinorous elements of the food-chains. It should be eliminated from the ponds if possible, since its presence decreases the food available to desirable herbivores and helps to sustain a large population of predators. Shrimps may be removed effectively with traps as well as with small-meshed nets. Some financial return is available because these shrimps are sold in the Honolulu fish markets.

Other feeders on the microbenthos occur in insufficient quantities or are sufficiently varied in their food habits so as not to present intolerable competition. In ponds having much brackish or fresh water

FIGURE 1.—Diagram illustrating the biotic interaction within Hawaiian fish ponds. Arrows point from the animals or plants eaten to those that eat them. Dominants are in underlined capitals, influents in underlined small letters, and subinfluents in small letters.

Gambusia replaces *Mollienesia* in importance. However, these ponds are few. The same type of control by seining would be practicable.

Milkfish have virtually no competitors for the larger benthos, since the amount of this food source taken by other species is insignificant.

Phyto- and zooplankton are of little practical utility in the mullet and milkfish ponds. Neither of these species takes nourishment from this food source. Indeed, barnacles and "nehu" (*A. purpurea*) are the only animals in the pond which do utilize plankton. Barnacles are a secondary food source to gobies and the carnivorous crabs, and the "nehu" a subinfluent as a source of food for carvinorous fish.

For a number of reasons the carnivore's place within the pond assemblage is complex. In regard to interspecific competition, we find that some compete with the more desirable herbivores by consuming the fry of these valuable species. Barracuda and possibly ten-pounders (Hiatt, 1947) may be placed in this category. Others do not prey upon the desirable herbivores, but instead consume herbivores and omnivores which do compete with mullet and milkfish for a source of nourishment. Bonefish, gobies, lizard fish, sleepers, and swimming crabs comprise the most important of these species. Several of the larger carnivores are valuable commercially (barracuda, ten-pounders, bonefish, and swimming crabs). Others have no sale value (lizard fish, sleepers, and gobies). Both lizard fish and sleepers are voracious feeders which consume several types of herbivores or omnivores commonly taken by species which are important commercially, and are, in turn, often preyed upon by these larger predators.

Probably the most striking, not to say paradoxical, result brought forth by this investigation is that, in spite of the intent of operators to rear herbivorous species, the ponds are replete with carnivores. Some of the detriment attributed to these species may be mitigated by the presence of great quantities of more easily captured sail-fins, mosquito fish, and shrimps. However, it has already been noted that these prey species are definitely undesirable constituents of the ponds.

If we examine the food-chains and food cycle more closely, it will be apparent that the rearing of carnivores for market purposes takes the income of the operators into the realm of diminishing returns. MacGinitie (1935) has stated that no link on the plant side of the chain can be of less weight than one toward the animal end. That is, plant weight at the beginning of the chain is greater than any weight following because energy, and therefore food, which is weight, is being dissipated all along the chain. It is difficult to ascertain the decrement in weight along the chains from plants to animal constituents. Attempts have been made. Birge and Juday (1922) calculated that the material which can be used as food by the plankton rotifers and crustaceans of Lake Mendota weighs twelve to eighteen times as much as these species. The fish which eat the crustaceans would weigh still less. Danish naturalists (*cit.* Pearse, 1939, p. 116) estimate that bottom feeding fish consume a total of about ten times their own weight

each year. MacGinitie (*op. cit.*) believes that 10,000 pounds of algae make 1,000 pounds of tiny crustaceans, 1,000 pounds of tiny crustaceans make 100 pounds of small fish, 100 pounds of small fish make 10 pounds of large fish, and 10 pounds of large fish make one pound of man. These proportions are different in Hawaiian ponds in that the most abundant small and large fish consume algae and its resultant detritus directly, thereby telescoping the usual food-chain relationships. The weight ratios probably are closer to the following: 10,000 pounds of algae and detritus make 1,000 pounds of herbivorous fish, 1,000 pounds of herbivorous fish make about 100 pounds of carnivorous fish or man. Since Hawaiian ponds contain many small carnivores of no commercial value which either terminate a food-chain or are subsequently consumed by larger predators, and since man harvests the larger carnivores, the weight ratios must be extrapolated through the terminal links of the food-chains. Thus, 100 pounds of small carnivorous fish will make about 10 pounds of large carnivorous fish, and 10 pounds of large carnivorous fish will make about one pound of man.

There is no doubt that the greatest yield in pounds of fish, and therefore in dollars, can be harvested from the herbivorous link of the food chains. Indeed, all salt-water fish ponds are operated upon this principle. Undesirable carnivores and worthless herbivorous competitors should be eliminated or greatly decreased in abundance. Efforts should be made to increase the production of the microbenthos and larger benthonic algae by applying appropriate inorganic fertilizers and by constructing shallow areas in the ponds where the light penetration would insure maximum plant growth.

However fraught with difficulties as the fish pond business of Hawaii seems to be, it can be made far more certain and lucrative if the operators would expend enough capital to alter the construction of the ponds, apply appropriate fertilizers, and remove species which are shown to be liabilities. It is clear that operators will have to put into it the same energy, economy, and serious consideration that they would put into the successful management of any other business. Enterprising operators will continue to secure a living because the mullet is to the Hawaiians a *sine qua non*. Less enterprising operators will eventually cease to depend upon income from the ponds and will permit them to fall into disrepair, a condition already responsible for the defunct condition of many Hawaiian ponds.

Summary

1. This study comprises an account of the general ecological features of the Hawaiian fish pond community, treats the food and feeding habits of the influent and subinfluent species, and includes a discussion of those elements within the biota and biotope which might be altered to increase the yield of marketable fish.

2. Changes in construction and operation of Hawaiian ponds have not evolved appreciably from primitive methods. These are com-

pared with the more modern fish pond development in the Philippine Islands and elsewhere in the western Pacific.

3. Hawaiian fish ponds are virtually autarchic. The available food supply within the ponds is almost totally dependent upon the physical features of the pond itself.

4. Sources of food for animal constituents are in order of their importance: microbenthos, detritus, larger benthonic algae, emergent halophytes, and plankton.

5. Animal constituents are separated into microbenthos feeders, detritus feeders, browsers, carnivores, omnivores, scavengers, and plankton feeders. Food and feeding habits are summarized for eleven fish (*Mollienesia latipinna, Sphyraena barracuda, Albula vulpes, Saurida gracilis, Eliotris fuscus, Anchoviella purpurea, Gnatholepis anjerensis, Gobiichthys papuensis, Gambusia affinis, Tetradon hispidis,* and *Caranx sexfasciatus*), four shrimps (*Leander debilis, L. pacificus, Bithynis grandimanus,* and *Crangon crassimanus*), and four crabs (*Scylla serrata, Portunus sanguinolentus, Podophthalmus vigil,* and *Panopeus pacificus*).

6. Biotic interaction is illustrated by a diagram of the food-chains and food cycle.

7. Interspecific competition is widespread in Hawaiian fish ponds. Mullet and milkfish utilize the same source of food to a large extent. Vast quantities of *M. latipinna* and *G. affinis* provide severe competition to both mullet and milkfish and thus are decided liabilities. Shrimps not only compete with marketable fish for sustenance but are one of the most significant links in the food-chains between plants and predators.

8. Means of elimination of sail-fins, mosquito fish, and shrimps are suggested.

9. Interaction between carnivores and between carnivores and herbivores is complex. Large carnivores prey upon desirable herbivores and likewise prey upon smaller, worthless carnivores.

10. At present, the tolerance of and marketing of carnivores is uneconomical because each successive link in a food-chain represents greatly decreased mass. Since the greatest yield in pounds of fish from Hawaiian fish ponds is to be obtained from herbivores, all rough herbivores and predators should be eliminated and all means available should be taken to augment the existing supply of benthos.

11. In spite of the fact that crabs contribute to income, their presence, especially that of the Samoan crab, is a source of considerable expense which may prove to be more than the revenue.

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RETURNS FROM NATURAL SPAWNING OF CUTTHROAT TROUT AND EASTERN BROOK TROUT

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INTRODUCTION

The present paper reports three seasons' experiments, from 1940 to 1943, designed to determine the number of fingerlings produced by natural spawning of cutthroat trout (*Salmo clarkii henshawi*) and eastern brook trout (*Salvelinus fontinalis*). Returns from natural spawning were secured by inducing wild trout to spawn in controlled sections of stream and later recovering the resulting fingerlings by diverting the water and pumping the pools dry. Similar methods were used by Berry (1934-1939). The experiments were conducted at the Convict Creek Experiment Station, 40 miles north of Bishop, California.[1]

These experiments were intended to increase the knowledge of natural production because both artificial and natural production should be considered in the management of trout fishing. In order to evaluate them the efficiency of each should be known.

All of the spawning trout used in these experiments, and also the data on cutthroat eggs, were supplied by the California Division of Fish and Game, for which the author thanks Mr. A. C. Taft, Chief, Bureau of Fish Conservation, and many men at the State hatcheries and egg-taking stations. The cutthroat came from Heenan Lake, of the Carson River drainage, in Alpine County, and the eastern brook were from Little Walker Lake in Mono County. At both lakes the State secures eggs by trapping the adults as they move up the inlets to spawn. The fish used here were secured from the same traps.

DESCRIPTION OF STREAM SECTIONS

The stream sections used in the experiments are former side-channels of Convict Creek which may be controlled with flashboard gates and screens. Otherwise, they are natural meandering meadow streams with deep pools and shallow gravel riffles. The general arrangement and operation of Convict Creek Experiment Station are described by Needham and Rayner (1939) and Needham and Slater (1944).

Each side-channel was designated by a letter, and the sections were numbered from the upper end down. Thus, Section E_2 is the second section in channel E, and E_3 is the next one downstream.

Section E_2 is 84 feet long and 6 to 15 feet wide. At the upper end is a pool and a short gravel riffle, but about three-quarters of the sec-

[1]This Station is operated by the U. S. Fish and Wildlife Service, with the cooperation of the U. S. Forest Service, the California Division of Fish and Game, and the Rainbow Club of Bishop.

tion is relatively deep and quiet. The quiet lower end has overhanging banks in some places and shallow, reedy margins in others, offering better shelter and more quiet water than any of the other sections. This feature might have contributed to high survivals obtained in this section. (See Table 3.)

Section E_3 is 41 feet long and from 4 to 9 feet wide. It has a pool at each end, with a gravel riffle between the two.

Section C_7 is 85 feet long and from 4 to 11 feet wide. The upper part is all riffle and the lower part is all pool. Gravel was placed in this section in May, 1940, and it made a fair spawning riffle that year, but most of it had washed away the following spring.

Section C_{1-4} is 437 feet long, and from 3 to 14 feet wide. It has a series of small pools and riffles. Some of the riffles are fine gravel.

Section D_{3-5} is 338 feet long and about 2 to 3 feet wide. It has a good series of small pools and riffles, with a bottom of fine gravel.

Section F is 506 feet long and from 2 to 5 feet wide. It is a relatively rapid section with a high proportion of riffles and small pools. Much of the riffle area is made up of course rubble, but one riffle is very fine gravel and sand. The gravel in this section is underlain by a dense mat of plant roots and silt, which may interfere with nest digging or proper aeration of buried eggs.

The flow in each section was about 2½ cubic feet per second.

Cutthroat Trout Experiments 1940

On May 6, 1940, four pairs of cutthroat trout were liberated in Sections E_{2-3}, and one pair in C_7. The spawning activities of these fish were described by Smith (1941).

After the trout apparently had finished spawning, the females were killed to determine how many eggs were retained. Two were removed from E_{2-3} on May 15. They measured 19 and 18.25 inches, fork length,[2] and had 3 and 109 eggs, respectively, remaining. It seemed likely that the latter fish had been removed too soon so the others were left in the section till June 14. The other two measured 19 and 19.25 inches and contained 4 and 3 eggs. The one female in C_7 was accidentally trapped and killed on a horizontal screen on May 23. She was 21.25 inches long and had 3 eggs left.

The four pairs of fish in E_{3-4} spawned from May 6 to 16, and resulting fry were first collected on June 15. The pair in C_7 spawned from May 12 to about May 15, and the first fry were collected on June 24.

Fry and fingerlings hatched in the experimental sections were collected throughout the summer as they moved down on horizontal screens through which the water fell. At the end of the summer, those which had remained and survived in the sections were collected by draining.

[2]Fork length is measured from the tip of the snout to the center of the fork of the tail. This is frequently referred to as total length.

Horizontal screens were used at the lower ends of the sections because it was impossible to back up water and slow down the current enough to permit the use of vertical screens. This condition was corrected the following summer, but in 1940 it resulted in having a fish-trap just below each spawning area. Fry which moved down on the horizontal screen were trapped there and killed.

The current from the redds or nests down to the screens was relatively rapid, and therefore the first collections are representative of fry which have just emerged from the gravel. Many still had traces of the yolk sac.

The fry showed a decided tendency to move down stream at night, which would seem to indicate that the movement is at least partially "voluntary," and not entirely due to the force of the current. In $E_{2\text{-}3}$, the early morning collections were 866 fry compared with 58 for the late afternoon from June 22 to September 16. The difference was not caused by birds picking fish off the screens because they had been effectively barred.

Table 1 shows numbers and sizes of fry recovered from the horizontal screens, as well as fingerlings recovered when the sections were drained in September. It may be seen that most of the downstream migration occurred soon after emergence from the gravel, and that an unknown proportion of the fry stayed in the section to be picked up after draining. The mortality sustained by the non-migrants before draining cannot be determined. Table 1 also shows the growth rate and range in size of fish spawned at the same time.

The total recoveries are minimal figures only. They are minimal for newly emerged fry, because the older fish picked up at draining were only the survivors from an unknown number of non-migrant fry. They are also minimal for the size in September because some of the fry collected from the screen in June and July probably would have lived until September if they had not been trapped.

Because the sections could not be drained at the start, of the season without interrupting other experiments, all wild trout naturally present were kept between the screens. They undoubtedly were predacious on, and competitive with, the experimental cutthroat. In $E_{2\text{-}3}$ there were 137 wild trout, average size 4.0 inches, range 1.9 to 10.25 inches, at draining in September. In C_7 draining revealed 13 wild trout present, average size 5.4 inches and range 3.35-8.15 inches. The wild fish were brown trout (*Salmo trutta*) except for 10 rainbow trout (*S. gairdnerii*) and 3 eastern brook trout. No fish spawned in the sections except the cutthroat placed there for that purpose. The 1940 experiment with cutthroat trout differed so much from later work that the results cannot readily be compared, yet it yielded some new information on numbers of newly emerged fry, fry migration, and the growth of naturally spawned fry.

TABLE 1.—*Recoveries of cutthroat trout from natural spawning experiments in 1940*

Date at start of 5-day period	Section E_{2-3} (4 Females Spawning in May)			Section C_7 (1 Female Spawning in May)		
	Number of fish	Average size in inches	Range in inches	Number of fish	Average size in inches	Range in inches
June						
15	109	0.83	0.71-0.91	0	.....	.....
20	1,063	0.87	0.79-0.95	3	0.90	0.94-0.95
25	376	0.89	0.83-1.06	184	0.92	0.83-1.06
30	107	0.92	0.79-1.14	179	0.93	0.95-0.98
July						
5	20	1.02	0.87-1.34	22	0.96	0.87-1.14
10	27	1.11	0.87-1.58	8	1.03	0.98-1.10
15	29	1.20	0.83-1.93	9	1.15	1.06-1.30
20	8	1.19	0.95-1.34	2	1.10	1.06-1.14
25	5	1.54	1.14-1.97	4	1.28	1.22-1.38
30	1	1.46	.....	0	.....	.....
August						
4	3	1.95	1.77-2.09	0	.....	.....
9	3	1.32	1.14-1.69	0	.....	.....
14	4	1.47	1.14-1.85	0	.....	.....
19	1	1.89	.....	0	.....	.....
24	1	1.81	.....	0	.....	.....
29	6	1.78	1.42-2.48	0	.....	.....
September						
3	2	1.93	1.89-1.97	0	.....	.....
8	5	1.54	1.46-1.61	1	1.97	.....
13	0	.....	.....	1[1]	1.61	.....
16[2]	....	.....	.....	30	1.97	1.61-2.60
18[3]	1	1.54	.....	....	.....	.....
19[2]	164	2.26	1.38-3.54	....	.....	.....
	Total fish recovered 1,935			443		
	Survival (to fry stage) 17 per cent			16 per cent		

[1]Total for 3 days.
[2]Section drained on this date.
[3]Total for 1 day.

CUTTHROAT TROUT EXPERIMENTS, 1941-42

Cutthroat spawning experiments were repeated with three stream sections in 1941 and one in 1942. The adults were liberated in May and removed after they had spawned. The young were retained between vertical screens and all the survivors were collected at one time, in September. (See Table 2.) The survival percentages therefore are complete, for the period of the experiment, which was not true in 1940.

Spawning activities were not watched as closely as they were in 1940 (Smith, 1941), but a number of things were noticed that might have contributed to the low survivals. The nests made by the two females in E_3 in 1941 did not overlap the way the two in that section did the year before (Smith, 1941). One spawned just above the riffle, but the other was driven away by the female above whenever she approached, and she finally spawned at the less favorable lower end of the riffle. Rocks were larger there and none of the pits she dug was as deep as the pits made by the other female, above the riffle. The bottom of each egg pit was composed of a dense mat of soil and stones held together by plant roots, rather than the loose clean stones of a typical egg pit. The nest defending action by a female cutthroat was not observed the year before (Smith, 1941).

In 1942 all three females in Section F deposited their eggs in the riffles, not in the smooth water just above, where trout usually spawn. Possibly they did this because the current was not fast enough above the riffles. During the spawning activities in 1942 about 400 eggs were found scattered over the mud in a quiet eddy 50 feet below one of the spawning riffles. The riffle above was made up of very fine gravel and sand and the mounds that were made by the female were gradually washed away by the current and even stirred up by the fighting males. The eggs might have been dug up by another female or washed out of the unstable gravel by the current or the fighting males.

An attempt was made to remove all resident trout from the sections before the spawners were liberated each May. The sections were drained and the pools pumped dry, but wild fish were found in September, nevertheless. (See Table 2.) The ones in C might possibly have come through the 8-mesh screen[3] that was used at the upper end, but 16-mesh screen was used on the other sections and the brown trout must have been in the gravel at the time of draining in May. A pair of brown trout was seen spawning in E_3 the previous November. Many newly emerged fry were found in both E_3 and F, in May, and an attempt was made to eliminate all of them by letting the section dry thoroughly and also by digging up the gravel beds. Seepage water prevented thorough drying, but it speaks well for the resistance of brown trout fry that so many survived till September. The high survival of the brown trout also makes it difficult to account for the complete absence of cutthroat survivors in Section F in 1941.

TABLE 2.—*Summary of natural spawning experiments with cutthroat trout, Convict Creek, 1941-1942*

Stream section	E_3	C_7	F	F
Date spawning started[1]	5-15-1941	5-15-1941	5-15-1941	5-13-1942
Number of female spawners	2	1	3	3
Number of male spawners	2	1	3	5
Estimated egg deposition	5,600	2,800	7,450	8,300
Number of fingerlings recovered	335	1	0	229
Estimated survival	5.98%	.04%	0	2.75%
Average size survivors (inches)	1.73	2.2	.....	2.2
Range	1.3-2.8	.....	.....	1.3-3.5
Date survivors collected	9-24-1941	9-18-1941	9-29-1941	9-24-1942
Competitive or predatory trout in in section[2]	3	44	450	16
Average size (inches)	4.1	3.3	2.7	3.8
Range (inches)	3.7-4.5	2.8-4.1	2.1-3.6	3.0-8.3
Lengths of females[3] (inches) number eggs in each and date removed	18.3-1 20.5-1 June 9	18.5-1 June 9	16.1-5 18.3-4 18.3-968 May 19	19.0-129 May 27[4] 19.0-2 19.0-4 May 29

[1]Spawning activities started in all sections within 24 hours after fish were liberated.

[2]All brown trout and, except for one 8.3 inch fish in F in 1942, all of them are probably from natural spawning that occurred in the sections the previous fall.

[3]Males were not measured but were about same size as females.

[4]One male and one female found dead on this date.

[3]Screen or "wire cloth" having 8 meshes to the inch. The spaces are therefore slightly less than ⅛-inch square due to the size of the wire.

The Survival of Cutthroat Trout

Survival is usually figured as a percentage of the number of eggs or whatever stage the animals may be in at the start of an experiment, but this is impossible with the present data without a reliable estimate of the number of eggs laid by each female.

It was not practicable to count eggs from enough individual Heenan Lake cutthroat spawners to give a reliable estimate, so the only information available for cutthroat of the size used are averages from the total number of females stripped and the total number of eggs obtained at the Heenan Lake egg-taking station. These are as follows:

Year	*Number of Females*	*Total Number of Eggs*	*Total Number of Eggs*
1940	214	761,740	3,560
1941	310	804,212	2,594
1942	320	802,400	2,508
1940-42	844	2,368,352	2,806

The individual spawners transported to Convict Creek appeared to be typical of the Heenan Lake stock in size, and therefore we probably will come about as near as possible to the true number of eggs deposited in the experimental sections if we use an estimate of 2,800 eggs per female.

Extrapolation from data by Calhoun (1944), based on cutthroat trout from the same region but smaller in size, lends some support to this estimate.

In cases where over 100 eggs were retained in the fish, a round number was subtracted to give the estimates shown in Table 2.

The survivals for cutthroat (Table 2) seem to be rather low, but some are higher than the survivals of Atlantic salmon obtained by Berry (1935-1939). He obtained survivals of 2.8 per cent and 2.6 per cent in two experimental areas where conditions were favorable and from 0.4 per cent to nothing where the eggs were exposed to floods or heavy silt. Berry recovered his fish as small fry, while in the 1941 and 1942 experiments at Convict Creek the survivors were recovered as fingerlings, about three months after emerging from the gravel. The minimal survival rates of 17 per cent and 16 per cent for fry from the 1940 Convict Creek experiments are considerably higher than Berry's figures.

The highest mortality rate in the life cycle of trout seems to come in the fry stage, soon after emerging from the gravel. White (1930), Hazzard (1932) and Hobbs (1940) have shown that the per cent of fertilization and the survival of eggs and alevins in the gravel is remarkably high. Hobbs (1940) found an average mortality to hatching of only 8.73 per cent based upon 358,111 specimens from 422 nests, and losses in the alevin stage were less than 1 per cent. Therefore, the great loss indicated by Berry (1939) and the present study probably occurs after the fry emerge from the gravel. In view of the wide divergence in results at Convict Creek and also the dangers of intro-

ducing unnatural or unfavorable conditions in such experiments, it seems probable that the cases of nearly complete mortality are not typical of natural spawning in favorable trout habitats.

Eastern Brook Trout Experiments

Eastern brook trout spawning experiments were carried on over three winters: 1940-1941, 1941-1942, and 1942-1943.

In each of the 3 years the trout were taken to Convict Creek in November and liberated in controlled sections of stream, with wire screens above and below them. Sometimes the fish, liberated late in one day, had a nest already started by daylight the next morning, at other times the fish did not start to spawn for several days. The spawning activities in Section E_2, 1940, were described by Smith (1941) and similar actions were observed the other two years.[4]

The fish were removed after spawning by shutting off the water and pumping out the pools because dip-netting proved impossible under the over-hanging banks and snags. On one occasion some of the stones over the nests became dry on top while the water was shut off, but the gravel always remained wet immediately under the surface. The recovered fish were measured and the eggs remaining in the females were counted. (See Table 4 for chronological and other data on each section.) Then the screens were removed and the creek was allowed to flow without interruption through the experimental channels all winter. There was nothing to prevent the free movement of wild fish and the eggs were left exposed to all the dangers of winter stream conditions. The following spring, before the fry had emerged from the gravel, fine mesh screens were installed above and below the spawning areas. Any wild fish present were thereby confined in the sections. In September, after the fry had grown large enough so that they could be picked up, the water was turned off, the pools pumped dry, and all the survivors, as well as all wild brown and rainbow trout were picked up. Thus each season there was a period of about ten months between the time the eggs were laid and the survivors were collected.

As Needham and Slater (1944) said, winters at the station are relatively severe. A minimum thermometer, left in one of the cabins over the winter of 1940-1941, went down to —20°F. and when the station was visited on April 2, 1941, the snow was still about three feet deep on the level. The main stream was open, as it usually is in winter, but some of the experimental sections were hidden under drifts.

During the night of April 4, 1941, there was a storm which is worth mentioning because it showed something about the winter conditions which brook trout eggs can withstand. The temperature dropped to 1.5°F. and snow from the treeless mountains drifted completely over the intake to Section E. At 8:00 a.m. the next morning, Section E had ceased to flow, though there was water in the pools. The lower part

[4]Other duties prevented the writer from being at the Convict Creek Experiment Station in November, 1942, and he is indebted to Daniel W. Slater for this part of the work.

was frozen over but free of snow. By 9:00 a.m. the pools were empty and the ice had fallen down to the bottoms. By noon the stream had worked its way under the snowdrift and E was flowing again, but no water had been flowing over the nests of the eastern brook trout for at least 3 hours. The highest return from natural spawning came from this section in which the nests had been above water twice, once from artificial draining and once from the snow dam.

The time when the fine-mesh screens should be installed to catch the fry was determined by sampling eggs from brown trout nests in the main stream on April 2 and 4, 1941. These nests had been made at the time the eastern brook were spawning the previous November and were still recognizable. Most of the eggs were still in the eyed stage, but a few had hatched. Judging by Embody's (1934) figures, it may be assumed that the brook trout were at about the same stage. He shows that brook trout develop a little faster than brown trout at 2°C. (35.6°F.) or colder, but at 3°C. (37.4°F.) or above the reverse is true. The average temperature of Convict Creek over winter is not known, but the temperature was both above and below 36°F while eggs were developing. For example: on April 2, 1941, water temperatures were: 8:10 a.m., 35°F.; 4:00 p.m., 44°F.; 7:45 p.m., 38°F. On April 5 at 8:00 a.m. the water was 32°F. and full of drifted snow and anchor ice. On February 8 and 9, 1942, the water temperature went from 32°F. in the morning to 39°F. in the afternoon each day. The bright sunlight at 7,000 feet above sea level warms the water very quickly on clear days.

On the basis of the above-mentioned examination of brown trout nests, the fine meshed screens were installed on April 23, 1941. This was not any too soon for fry were first seen between the screens 10 days later. The margin of safety in each experiment was rather small (see Table 4), but nevertheless the screens apparently were always in place before any fry had emerged from the gravel.

The first fry seen in 1941 was found dead against the lower screen in E_2. It was only 0.7 inch long and the yolk-sac scar had not yet healed over, indicating that it had but recently come out of the gravel. No brook trout of the year was ever recovered in any of the sections below those used for natural spawning. The other sections were used for other experiments each year but 1943, and if brook trout had been present, they would have been found.

The most complete observations on the emergence of the fry from the gravel was secured in 1942, in Section $D_{3\text{-}5}$. On April 26, 7 days after the screens were installed, about 12 fry were found swimming over a nest. Careful scrutiny had failed to reveal any fry before that date. They hugged the bottom closely, often lying just down-stream from small stones. On lifting one small stone, about 2 inches across, 5 fry were found clustered together, apparently ready to come up. One free-swimming fry was seen to burrow back into the gravel when startled. The fry hung over the nesting area for several days before

TABLE 3.—*Summary of natural spawning experiments with brook trout,* Salvelinus fontinalis, *Convict Creek Experiment Station, 1940-1943*

Stream section	E_3	E_2	E_2	C_{1-4}	D_{3-5}	D_{3-5}	Totals
Date spawning started	11-16-40	11-11-41	11-15-42	11-15-40	11-10-41	11-11-42	Nov. '40, '41, '42
Number of female spawners	3	2	2	3	3	3	17
Most probable number of eggs	1,535	925	527	1,651	1,969	1,607	7,991
Standard error limits	1,273-1,846	758-1,128	400-669	1,402-1,945	1,678-2,311	1,397-1,847	7,444-8,576
Number of fingerlings recovered	651	253	19	67	227	97	1,314
Most probable survival (per cent)	42.4	27.4	3.6	4.1	11.5	6.0	16.4
Standard error limits (per cent)	51.1-35.2	33.4-22.4	4.8-2.8	4.8-3.4	13.5-9.8	6.9-5.3	17.7-15.3
Average size survivors (inches)	2	2.4	2.9	3.0	2.4	2.7	2.3
Range (inches)	1.4-3.0	1.6-3.4	2.5-3.2	2.5-3.5	1.8-3.4	2.0-3.3	1.4-3.5
Date survivors collected	9-24-1941	9-25-1942	9-15-1943	9-22-1941	9-9-1942	9-15-1943	Sept. '41, '42, '43
Competitive or predator trout in sections[1]	264	62	40	107	18	124	615
Average size (inches)	3.0	3.4	5.2	4.4	4.5	3.7	3.6
Range (inches)	1.7-5.9	2.1-8.2	2.9-8.2	1.2-7.7	2.8-8.2	2.6-8.0	1.2-8.2

[1]These are about 60 per cent brown and 40 per cent rainbow trout that were unavoidably retained between the screens.

TABLE 4.—*Miscellaneous data pertaining to spawning experiments with brook trout,* Salvelinus fontinalis, *at Convict Creek Experiment Station, 1940-1943 (See Table 3)*

Stream Section	E_2	E_2	E_2	C_{1-4}	D_{3-5}	D_{3-5}
Season	1940-41	1941-42	1942-43	1940-41	1941-42	1942-43
Adult fish liberated	2 M 2 F Nov. 14, 1940 1 M 1 F Nov. 15, 1940	3 M 2 F Nov. 9, 1941	3 M 2 F Nov. 10, 1942	2 M 2 F Nov. 14, 1940 1 M 1 F Nov. 15, 1940	4 M 4 F Nov. 9, 1942	5 M 4 F Nov. 10, 1942
Spawning activities observed	Nov. 16-23 1940	Nov. 11-14 1941	Nov. 15-18 1942	Nov. 15-18 1940	Nov. 10-14 1941	Nov. 11-17 1942
Adult fish removed	Nov. 27	Nov. 18	Nov. 19	Nov. 26	Nov. 18	Nov. 19
Length of females and number of eggs left in each	9.4 in. 4 9.5 in. 98 9.6 in. 157	7.9 in. 17 9.2 in. 1	7.2 in. 104 7.1 in. 28	9.1 in. 1 9.3 in. 6 9.5 in. 40	10.9 in. 1 9.4 in. 16 9.8 in. 0 10.4 in. all[1]	9.3 in. 11 7.3 in. 0 7.0 in. 3 8.3 in. 3
Lengths of males	8.9-9.8 in.	About 9.8 in.	7.7-8.0 in.	9.6-9.9 in.	About 9.8 in.	6.8-9.4 in.
Fine mesh screens installed	April 23, 1941	April 19, 1942	April 16, 1943	April 23, 1941	April 19, 1942	April 16, 1943
Fry first seen	May 3	April 28	May 3	.....	April 26	April 27

[1]This female was full of ripe eggs and had not spawned at all. The hind end of the body cavity was plugged by a mass of empty egg shells, possibly left from incomplete artificial stripping or failure to spawn some year previously. This fish was not included as a spawner in Table 3.

any were seen above or below, but they spread over the section and became more and more numerous during the next 2 weeks.

It is highly improbable that any brook trout, except the ones under observation, spawned in the experimental sections. The spawning gravel in E_2 was covered each year with coarse mesh screens weighted down with large stones to prevent other trout from spawning in the same area. This could not be done in other sections because the gravel areas were too wide-spread and scattered. Furthermore, brook trout are very scarce in Convict Creek, and no brook trout of the year was found in any other stream section.

Only 4 eastern brook trout were found out of a total of 2,181[1] wild trout collected from other sections in the fall of 1941, and in 1942 one wild eastern brook trout was found out of 806[1] wild trout recovered in other sections. These five fish were all at least three years old.

Returns from Natural Spawning of Eastern Brook Trout

The eastern brook trout spawning experiments give a few figures on numbers of fingerlings produced by a given number of adults of known sizes, but they do not give any information on the per cent survival without some estimate of the number of eggs laid. Unfortunately, the best estimate is none too good, because very little has been done on the correlation between numbers of eggs and sizes of eastern brook trout.

It was not practicable to obtain an adequate sample of Little Walker Lake fish for egg counts, and therefore a study of the relation between numbers of eggs and size was made on wild eastern brook trout from a number of sources. This study was intended to show the probable number of eggs for fish of various sizes and also the variation. The variation, which may be expressed as standard error, is especially important in the present investigation because we are endeavoring to establish a reliable estimate of the number of eggs laid by a few individuals rather than the number of eggs laid by a large population, such as a salmon run.

Number of eggs plotted against length of fish showed a distinct curvilinear correlation, as indicated by Ricker (1932). The log of egg count plotted against the log of fish length (Fig. 1) showed a straight line relationship with a high degree of correlation ($r = .88$). The number of eggs is, obviously, related to the weight or volume of the fish rather than to the length. Only those fish between 7 and 15 inches long were used in the calculations, because these were more nearly the size of the females used in the experiments and because the fish under 7 inches long appeared to be an aberrant group, probably due to slow growth and maturity at a small size in small, cold streams.

The data upon which Figure 1 is based was generously furnished to the author by several people, largely from unpublished data. Dr. H. S. Davis furnished counts from 15 fish, all less than 7½ inches long,

[1]This figure does not represent the total number of wild trout removed at the station, but covers only fish from those sections in which no eastern brook trout were used experimentally.

from the Pisgah National Forest of North Carolina; Dr. Paul R. Needham furnished 4 from Angora Lake and one from Convict Creek, California; and Dr. William E. Ricker furnished 33 egg counts from Ontario, 22 of which were from Mad River. Some of the data furnished by Dr. Ricker appeared in the graphs in his 1932 publication.

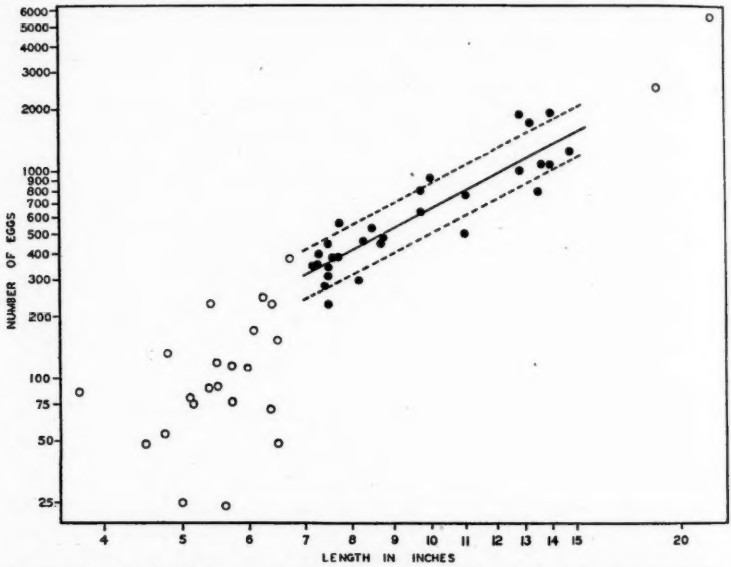

FIGURE 1.—Numbers of eggs in 54 wild eastern brook trout plotted against lengths of fish on logarithmic scale. Only the egg counts from 29 fish between 7 and 15 inches long were used in calculations. These are solid black dots. Dotted lines represent one "standard error of estimate."

Egg counts published by Titcomb (1897) were not used in the calculations because, as Titcomb said, "Some of these trout had apparently dropped part of their eggs before being captured."

Vladykov (1940), gave a good series of average egg counts for brook trout of various lengths, but since his data do not give information on the variability, they were not used in the present calculations. His averages are much lower than indicated by the regression line in Figure 1, and if they had been used in the present calculations, the estimated survival rates would have been higher.

Estimates of the number of eggs laid by the brook trout at Convict Creek were based on the regression line of Figure 1. (See Ezekiel, 1941.) For each stream section the mean length of the spawning females was determined and the logarithm of this mean found. Then,

from Figure 1, the logarithm of the number of eggs corresponding to this mean length was found and the antilogarithm found by consulting a table. This value was taken as the average (geometric mean) number of eggs per female, and, multiplied by the number of females, gave an estimate of the total number of eggs contained in the females that spawned in the given stream section. The upper and lower limits were determined as the antilogarithms of the mean logarithm plus and minus the standard error of the mean logarithm; each result then being multiplied by the number of cases. These limits may be interpreted as "fiducial limits" within which about 67 per cent of the values may be expected to fall.

In data conforming to the assumptions on which these calculations are made and involving the relationship between length and volume, a greater range of variations is to be expected above than below the geometric mean and this treatment has the advantage of taking this fact into consideration.[1]

Eggs remaining in the body cavities of females after spawning were not included in the potential egg deposition because trout shed almost all of their eggs under normal conditions. Hobbs (1937) says that 14 brown trout that had spawned naturally had retained an average of 6.7 ova, and 22 salmon (*Onchorhynchus tschawytscha*) retained an average of 8 ova.

The number of eggs retained by the trout used in the Convict Creek experiments probably is not typical because there is always a danger of interrupting the normal spawning progress in such experiments, especially with the brook trout that spawn in the fall and therefore cannot be left unmolested for many days without the expense of maintaining the experiment unduly long. There is also a possibility that some factor, such as unfavorable conditions in the experimental areas, the unavoidable handling, or disturbances during spawning, might have upset the normal behavior of either sex.

The success of natural spawning by brook trout in the Convict Creek experiments is presented in Table 3. The experiments show the rather remarkable fact that as many as 40 or 50 per cent of the eggs laid may live long enough to grow into two-inch fingerlings, in spite of possible predation, competition from other trout and other natural hazards. Even the lowest survival is considerably better than the highest (2.8%) obtained by Berry (1939) for Atlantic salmon. A comparison with Berry's data shows, however, some other points of interest. Though his survivals were lower when figured as percentages, they were more nearly the same in terms of number of young per spawning adult. The two more successful experiments with cutthroat trout, summarized in Table 2, also produced similar results in terms of young per spawning adult. Whether this is an example of Nature's tendency to balance great productive capacity with great prodigality, or whether it is

[1]The author is indebted to Dr. Willis H. Rich, Stanford University, for suggesting this statistical treatment.

the effect of some limiting factor such as space, we have yet to learn. One thing is known, and that is that eastern brook trout cover their eggs much more carefully than cutthroat trout (Smith 1941) and presumably they are more careful than Atlantic salmon.

In view of the tendency shown by cutthroat fry at Convict Creek to spread out and move downstream (possibly upstream, also), space might be important in experiments such as these. This is partially borne out by the fact that the two highest survivals were obtained in Section E_2, which had more and better pool area than the other sections.

The low survival in section E_2, in 1942-43, compared with the two previous seasons, might have been caused in part by a change that took place in the spawning gravel. Erosion and a slight change in the channel had washed out much of the finer gravel sometime between September, 1942 and April, 1943, leaving coarser gravel on the bar where all of the spawning took place in November of 1940 and 1941. This change may have washed out eggs or, if it occurred before spawning, it may have made nest building difficult for the relatively small females using the area in November 1942.

In the discussion of survival of cutthroat eggs, above, reasons were given for believing that most of the mortality occurred after the fry had emerged from the gravel. The same arguments apply to eastern brook trout, and there might be further indication of this in the fact that the highest returns were both secured in section E_2, where the shelter appeared best.

Summary

Experiments were conducted over three seasons to determine the number of fingerlings or fry produced by natural spawning of cutthroat (*Salmo clarkei henshawi*) and eastern brook trout (*Salvelinus fontinalis*). Returns were secured by inducing wild trout to spawn in controlled and screened sections of stream. The resulting fingerlings were collected by diverting the water and pumping the pools dry.

The cutthroat spawned in May and the fingerlings were recovered in September each year.

During the first summer, horizontal screens, acting as fish traps, were used below the cutthroat spawning areas so that some fry were trapped soon after emerging from the gravel. Other fry remained in the section and were recovered in September. The minimum survival obtained was about 17 per cent of the estimated number of eggs laid. Data were obtained on fry migration and the growth of fry spawned at the same time.

Vertical screens were used in all other experiments so that all survivors were collected in September. Survivals of cutthroat ranged from nothing to about 6 per cent of the estimated number of eggs in four trials, each trial sections containing 1 to 3 female spawning trout.

Eastern brook trout spawned in November. Screens were removed over winter and fin mesh screens were installed before the fry emerged from the gravel each spring. The surviving fingerling were recovered in September each year. Recoveries from six trials gave survivals of from 3.6 to 42.4 per cent, with an average of 16.4 per cent. Two to three females spawned in each trial stream section.

A study was made of the relationship between numbers of eggs and size of adult wild eastern brook trout. A straight-line relationship was found between logarithms of the numbers of eggs and lengths of fish. Estimates of the numbers of eggs deposited were made from the regression line obtained.

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THE PHYSIOLOGICAL EFFECT OF SODIUM CHLORIDE UPON BROOK TROUT

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ABSTRACT

Feeding sodium chloride in gelatin capsules to brook trout caused a rise in blood salt when amounts of 10, 15, 20, and 25 milligrams were ingested. No effect on the chloride level was found when 5 milligrams were fed. An edema resulted from feeding the two higher levels. This disappeared in the 20 milligram experiment with no loss of fish, but caused a mortality in the 25 milligram level. The absorption curves for salt were similar to those described for carbohydrates. Excretion curves were found to be curvilinear, but showed a break in the two higher levels with the appearance of edema. It was necessary to feed between 0.91 and 1.82 grams of salt per kilogram of body weight to produce a rise in blood salt and between 2.72 and 3.64 grams per kilogram to cause an edema.

Salt baths of 3.0 and 5.0 per cent caused an increase in salinity of the blood of trout. A 2.5 bath had no such effect. For the shorter periods of immersion, an increase in blood salt was quickly eliminated upon return of the fish to fresh water, but the baths of longer duration produced a more prolonged effect. The concentration of a salt bath determines the period of immersion since the greater the concentration, the more rapid the change of blood salinity and the fish is unable to make the proper adjustments. The level of blood chlorides reached appears secondary to the rate of change of salinity.

INTRODUCTION

For many years fish-culturists have used salt in the artificial propagation of trout both as salt baths and the inclusion of the material in the diet. Some fish-culturists maintain that salt is an indispensable aid in raising trout while others believe that it has little if any beneficial effect. When added to a diet, salt does combine with certain meats to form a mass of rubber-like consistency that holds the ingredients and prevents much loss of nutrients in the water (Tunison, 1940). It has also been claimed that salt results in an increased rate of growth when added to the diet.

The effect of external salt baths upon the physiology of the fish has received considerable attention in the past. That such baths result in a change in the osmotic pressure of the fish's body fluids seems certain. Whether this change is due to the actual entrance of salt into the body, or merely to an exchange of water has not been clearly demonstrated. Sumner (1906) found a change in certain marine animals when the salinity of the water was altered. Greene (1905) reported a drop of

[1]The Cortland Hatchery is operated under a cooperative agreement between the Fish and Wildlife Service, the New York State Conservation Department and Cornell University.

17.9 per cent in the concentration of the blood of salmon on their freshwater spawning beds. He pointed out that such changes might not be due to salinity alone, but that the metabolic modifications of the body of the fish caused by the 8 to 12 weeks in fresh water without feeding might alone account for the decrease in blood concentration. Kaplanski (1937) demonstrated that there was a change in chloride content of the blood of carp held in salt solutions over a period of time. Other workers have shown similar changes with different species of fish (Scott, 1910; Garrard, 1935; Grafflin, 1935). Bond *et al.* (1932) reported a considerable change in the salt content of the blood of hag-fish when the animals were placed in various concentrations of sea water. The degree of change was dependent upon the concentration employed. Garry (1905) stated that there was little if any change in the concentration of the blood of *Anguila* when the animals were subjected to various solutions. However, if the skin were abraded, a great change occurred, resulting in death if the fish were placed in either fresh water or concentrated solutions. Death could be prevented by using a solution isotonic with the body fluids of the animal. Krogh (1937, 1938, 1939) demonstrated that there was an actual entrance of salt into the body of the fish under certain controlled conditions. The fish were first placed in distilled water and allowed to remain until a definite reduction in blood chlorides occurred as measured by the salt content of the distilled water. The fish were then placed in concentrations of salt well below the concentration of the fluids of the body. Under these conditions an entrance of salt was observed. Krogh stated that the experimental studies of the uptake of salts must be preceded by a period of definite body-chloride reduction and the animals then placed in a solution of a concentration well below that of the body fluids.

Brockway (1940) reported that salt was removed from the solution by both goldfish and brown trout. He demonstrated marked increases in chloride content of both species when they were subjected to 3-percent salt baths. Upon removal to fresh water the salt content of the blood quickly returned to normal, provided the length of the bath was not longer than one-half hour.

The effect of ingested salt upon the fish has received far less attention. Tunison *et al.* (1938) fed a diet containing 13 per cent salt and reported no ill effects. However, it is well known that excessive amounts of salt fed to higher animals results in the formation of an edema, which, unless corrected, will cause the death of the animal.

The present series of experiments were made upon brook trout in an effort to more clearly show the effect of sodium chloride upon the physiology of the fish. The experiments consisted of both ingested amounts and baths of various concentrations.

THE ABSORPTION OF SALT FROM THE GASTRO-INTESTINAL TRACT

Brook trout averaging 5.6 grams in weight were fed various amounts of sodium chloride in gelatin capsules. The fish were placed in aerated aquaria and at intervals some were removed. The blood, gastro-intestinal tract and the water of the aquaria were analyzed for salt at these times.

The blood for analysis was obtained in a manner described previously for blood counts (Phillips, 1940). A special pipette was used for collecting the sample. This consisted of a capillary tube drawn to a medium fine point and graduated from 0.01 to 0.05 cc. Samples as small as 0.01 cc. were found sufficient to obtain suitable values, but whenever possible larger samples were used.

Twelve fish were used for each time interval and values reported are the average for the 12 observations.

The sodium chloride was determined by the silver iodate method (Lumetron, 1940) and the results were read in a colorimeter using filter No. 420.

Table 1 is a summary of the results following the feeding of various levels of salt. The milligrams absorbed and excreted were actually observed and the milligrams retained are the difference between these two. The milligrams present in the blood system were caluculated from the rise in blood chlorides per 100 cc. of blood. For this calculation the ratio of Welcker (1854) was used in which the amount of blood is assumed to be 2 per cent of the body weight. For fish of the size used in these experiments the amount of blood was estimated as 0.112 cc. That the formula of Welcker is subject to error is shown by the work of McCay (1928) in which he found that the amount of blood should be from 3 to 5 per cent of the body weight and in one instance it was found to be as high as 8 per cent. However, based upon the amount of blood that was obtained for the analyses, it is thought that Welcker's ratio best suited the purpose.

In Table 2, the results are summarized in terms of percentages. The percentages absorbed and excreted are based upon the level fed. The percentages of rise and fall in blood chloride are based upon control lots that were maintained for each series of experiments. The average "normal" chloride level of the blood was found to be 496 milligrams per 100 cc. of blood. This agrees reasonably closely with others in the literature.

The values of Table 2 are shown graphically in Figure 1, in which the rates of absorption, excretion and rise and fall in blood chlorides may be compared. All curves were fitted by inspection as scatter graphs.

Feeding 5 milligrams of salt resulted in no increase in the blood chloride of the fish. The salt was excreted almost as quickly as it was absorbed. The fish showed no distress and appeared perfectly normal.

The rate of absorption was somewhat slower than those found for the higher concentrations of salt.

Fish fed 10 milligrams had a definite increased salt content of the blood. However, the total milligrams of salt present in the blood was far less than the amount retained by the fish's body (Table 1). Much of the salt was apparently elsewhere in the fish's body, probably the body fluids. As the rate of absorption became less, the blood chlorides

TABLE 1.—*Milligrams of sodium chloride absorbed, excreted, and retained by the body and retained in the blood of trout following the feeding of various amounts of salt in gelatin capsules*

Amount in milligrams fed per fish	Time in hours	Milligrams absorbed	Milligrams excreted	Milligrams retained by body	Milligrams retained[1] in blood of the fish
5	3.0	1.34	1.17	0.17	0
	6.0	2.16	1.56	0.60	0
	9.0	2.71	2.56	0.15	0
	15.0	3.18	3.38	—0.20	0
	24.0	4.05	4.01	0.04	0
10	1.5	3.64	0.00	3.64	0.061
	3.0	4.99	2.39	2.60	0.138
	4.5	6.35	3.21	3.14	0.111
	6.0	7.90	6.31	1.59	0.044
	7.5	8.75	7.24	1.51	0.022
	9.0	9.09	8.46	0.63	0.033
	15.0	9.34	8.66	0.68	0.022
15	1.5	4.26	2.85	1.41	0.061
	3.0	6.89	3.89	3.00	0.172
	4.5	7.64	4.97	2.67	0.122
	6.0	11.55	6.10	5.45	0.216
	7.5	12.10	9.60	2.50	0.178
	9.0	12.88	10.00	2.88	0.138
	15.0	14.40	10.32	4.08	0.067
	24.0	14.50	14.94	—0.44	0.049
20	1.5	6.18	2.00	4.18	0.061
	3.0	9.29	2.79	6.50	0.244
	4.5	11.61	4.38	7.23	0.178
	6.0	15.58	4.89	10.69	0.232
	7.5	16.00	7.18	8.82	0.272
	9.0	17.37	7.80	9.57	0.199
	15.0	18.24	10.82	7.42	0.183
	24.0	19.03	18.06	0.97	0.049
25	1.5	9.50	2.24	7.26	0.148
	3.0	11.21	4.27	6.94	0.227
	4.5	15.27	8.89	6.38	0.239
	6.0	17.00	8.48	8.52	0.249
	7.5	18.74	12.50	6.24	0.232
	9.0	21.48	12.73	8.75	0.266
	15.0	23.02	12.23	10.79	0.260
	24.0	23.72	15.98	7.74	0.122

[1]Total blood based on Welcker formula of 2 per cent body weight as blood.

dropped so that for all practical purposes it had reached the normal level by the end of 6 hours. The rate of excretion was considerably slower than the rate of absorption (Figure 1) and the salt was entering the fish's body faster than it could be handled. No ill effects were noted.

Following the feeding of 15 milligrams of salt a still higher rise in blood chlorides was found. The length of time required for the blood chlorides to again reach a normal level was much longer than when 10 milligrams were fed. The rate of excretion fell still farther behind the rate of absorption. The salt retained by the fish's body was far in ex-

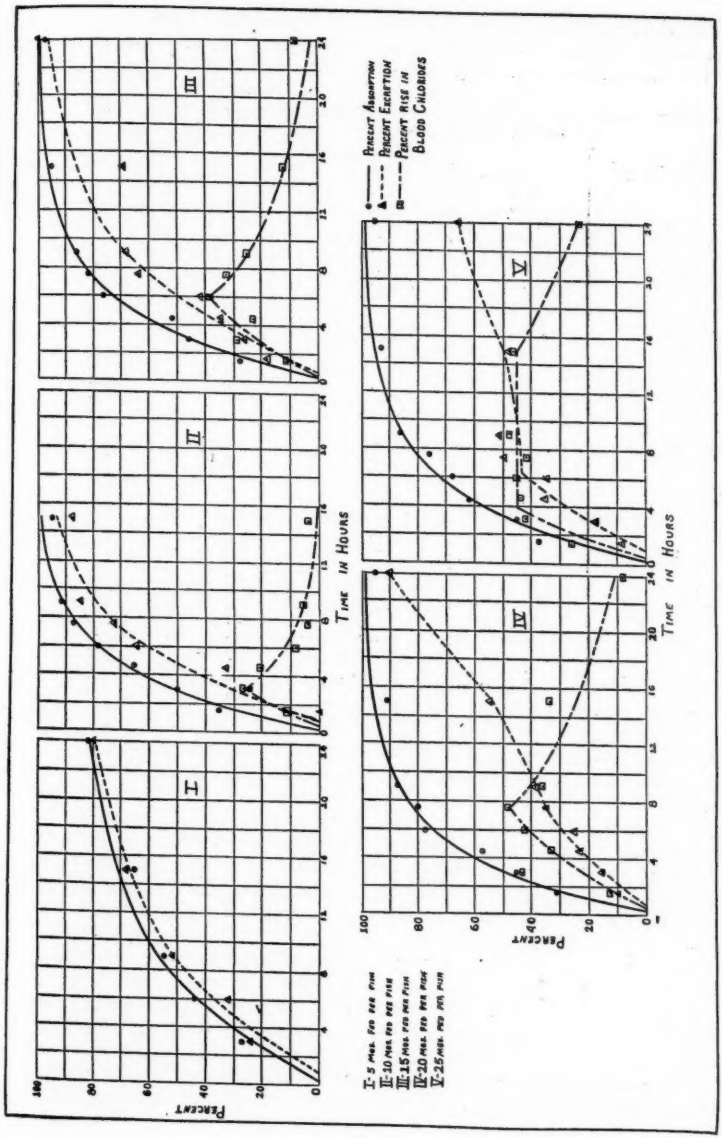

FIGURE 1.—Percentage absorption and excretion of 5 levels of sodium chloride fed in gelatin capsules to brook trout, together with curves showing the percentage rise and fall in blood salt

cess of that found in the blood. About 6 hours after feeding the fish were nervous and a few capsules had been regurgitated. This accounts for the somewhat erratic appearance of the excretion data.

TABLE 2.—*Summary of sodium chloride absorption studies in terms of per cent. All values expressed to nearest whole per cent.*

Amount in milligrams fed per fish	Time in hours	Percentage absorbed	Percentage excreted	Percentage rise in blood chlorides
5	3.0	27.	23.	0.
	6.0	43.	31.	0.
	9.0	54.	51.	0.
	15.0	64.	68.	0.
	24.0	81.	80.	0.
10	1.5	36.	0.	11.
	3.0	50.	24.	26.
	4.5	64.	32.	20.
	6.0	79.	63.	8.
	7.5	88.	72.	4.
	9.0	91.	85.	6.
	15.0	93.	87.	4.
15	1.5	28.	19.	11.
	3.0	46.	26.	29.
	4.5	51.	33.	22.
	6.0	77.	41.	39.
	7.5	81.	64.	32.
	9.0	86.	67.	25.
	15.0	96.	69.	12.
	24.0	97.	100.	9.
20	1.5	31.	10.	11.
	3.0	46.	14.	44.
	4.5	58.	22.	32.
	6.0	78.	24.	42.
	7.5	80.	36.	49.
	9.0	87.	39.	36.
	15.0	91.	54.	33.
	24.0	95.	90.	9.
25	1.5	38.	9.	27.
	3.0	45.	17.	41.
	4.5	61.	36.	43.
	6.0	68.	34.	45.
	7.5	75.	50.	42.
	9.0	86.	51.	48.
	15.0	92.	49.	47.
	24.0	95.	64.	22.

When 20 milligrams of salt were fed, the salt level in the blood was increased and the period required for approaching normal was longer than the two previously described levels. The rate of excretion was very slow and a break occurred in the curve about 7.5 hours after feeding and lasted through the 15-hour period. The amount of salt retained by the body was much greater than that present in the blood stream, as found in other experiments of this group. An edema appeared among the fish about 6 hours after feeding and explains the break in the excretion curve. Since some of the salt entering the body was present in the cavities, it was no longer available for excretion. An analysis of the body fluid showed a chloride content of 850 milligrams per 100 cc. of fluid. The edema had largely disappeared by the end of 15 hours and had disappeared completely at the end of 24 hours. The fish were all listless and breathing with difficulty. Although no mortality resulted, some of the fish were found on their sides between 6 and 8 hours after feeding. Several capsules were regurgitated dur-

ing the course of the experiment. By the end of 24 hours the chloride level of the blood was approaching normal and the fish gave no evidence of distress.

The feeding of 25 milligrams per fish produced a marked rise in the salt content of the blood that was extremely slow in returning to normal. For a period between 4 and 15 hours after feeding the salt the level showed little tendency to drop and the fish were weak and listless. The excretion curve shows a pronounced break at the end of 4 hours which lasted through the 15 hour period. The appearance of an edema 4 hours after feeding, which lasted throughout the remainder of the experiment, accounts for the break in the excretion curve. This would also account for the maintenance of the high chloride level of the blood during the same period. At the height of the edema the excess fluid completely filled the body cavity and an analysis showed a salt content of 1,000 milligrams per 100 cc. of fluid. By the end of 24 hours the edema was less severe and the salt content of the fluid had dropped to 800 milligrams per 100 cc. of fluid. The fish remaining alive at the end of 24 hours were extremely weak and by this time 66 per cent of the fish had died. These were the only losses experienced during the experiments.

In all cases the amount of salt found to be present in the blood of the fish (Table 1) was far less than the amount retained in the body. Much of the salt must have been stored elsewhere in the body. Since high levels of salt in the blood would cause an osmotic upset with the other tissues and fluids of the body, such an exchange of salt would appear reasonable. In addition the body of the fish probably also absorbed water to dilute the salt and these two processes probably best explain the appearaice of edema.

The absorption curves were strikingly similar in trend to those found for various carbohydrates (Phillips *et al.*, 1940). The percentage absorption was essentially the same for all levels except the 5 milligram experiment, where the salt was absorbed at a slower rate.

The weakness observed in all experiments, except the lowest level, can probably be explained by the osmotic upset that must have occurred in the fish due to the absorption of such large amounts of salt. It is astounding that such high levels of salt in the blood could be reached without more mortality than was observed.

The reduction of the levels of salt fed in terms of grams per kilogram of body weight, show that it is necessary to feed between 0.91 and 1.82 grams per kilogram of body weight to cause a rise in blood cholrides and between 2.72 and 3.64 grams to produce an edema. In usual hatchery practice the level necessary to produce an edema would not be reached, since foods extremely high in salt are not fed to fish. Theoretically it would be possible to feed sufficient salt to cause a rise in blood chlorides. However, salt is extremely soluble and it is improbable that all the salt present in the diet reaches the fish. This is the probable explanation for the lack of ill effects in the experiment

of Tunison *et al.* (1938) when levels as high as 13 per cent were fed.

There appears to be little doubt that at least a large part of the change in chloride level of the blood in these experiments was due to the actual entrance of salt into the body and not merely to an exchange of water, thus concentrating the blood and diluting the salt present in the tract. The excretion curves, appearance of edema, the high level of body retention of salt and stomach recoveries all support this contention.

One trial was made in which 50 milligrams of salt were fed. The trout became nauseated and the capsules were regurgitated. The experiment was discontinued.

The Absorption of Salt from Baths

Fish were immersed in salt baths of strengths of 2.5, 3.0 and 5.0 per cent for intervals shown in Table 3. The fish's blood was analyzed immediately upon removal from the bath and for periods following to determine the rate of return to normal. It was not possible to use fish the same size as those used in the absorption studies. The trout used in these experiments averaged 12.0 grams in weight. The experiments were made in aerated salt baths and the fish were held in aerated aquaria until killed for analysis. The water temperature was 50° F.

The method of collecting the blood sample and the method used for analysis was identical with that of absorption studies.

The results have been summarized in Table 3. They are based upon the normal level of 496 milligrams of salt per 100 cc. of blood. Each value represents an average of eight observations.

Fish immersed in a 2.5 per cent salt bath for 30 minutes showed no increase in blood salt. The increase of the period to 60 minutes gave similar results. No distress was evident during either trial. A longer period of immersion was not attempted since it would not be usual hatchery practice.

The use of a 3-per-cent salt bath for 30 minutes produced an increase in the blood salt, which quickly returned to normal when the fish were placed in fresh water. The fish were somewhat distressed when removed from the bath.

A 60-minute bath in 3 per cent salt resulted in a great increase in blood salt. The fish were highly distressed when removed from the bath and about 50 per cent had turned over on their sides, but none of them died. A period of 48 hours was required for the blood to again reach a normal level. It is though that aeration of the salt bath prevented the loss of fish experienced by Brockway (1940) in a similar experiment.

The use of a 5-per-cent salt bath for 10 minutes resulted in an increase in blood chlorides which although high. was far below that shown by the 60-minute, 3-per-cent treatment. At the end of the 10-minute period all fish were turned over and breathing with difficulty. However, there was no loss among the experimental animals and the

TABLE 3.—*Summary of the effect of sodium chloride baths upon the salt content of trout blood*

[All per cent values expressed to nearest whole per cent]

Time in hours	2.5 per cent bath				3.0 per cent bath				5.0 per cent bath			
	30 minute		60 minute		30 minute		60 minute		10 minute		15 minute	
	Milligrams rise per 100 cc. blood	Percentage rise	Milligrams rise per 100 cc. blood	Percentage rise	Milligrams rise per 100 cc. blood	Percentage rise	Milligrams rise per 100 cc. blood	Percentage rise	Milligrams rise per 100 cc. blood	Percentage rise	Milligrams rise per 100 cc. blood	Percentage rise
0	0	0	0	0	105.	21.	329.	66.	124.	25.	155.	31.
1	0	0	0	0	88.	18.	289.	58.	59.	12.	87.	18.
2	0	0	0	0	50.	10.	178.	36.	28.	6.	144.	29.
4	0	0	0	0	25.	5.	108.	22.	10.	2.	107.	22.
6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	120.	24.
24	.....	.....	.....	.....	.....	.....	80.	16.	.....	.....	109.	22.
48	.....	.....	.....	.....	.....	.....	14.	3.	.....	.....	63.	13.

blood salt had returned to normal by the end of 4 hours. It is thought the change in salinity of the blood was so rapid, due to the stronger concentration of salt, that the fish were unable to adjust their bodies to the new condition. This is the possible explanation for the higher blood chloride found in the 60-minute 3-per-cent bath. The change in salinity of the blood in this case was at a slower rate, due to the weaker concentration of the bath, and the fish were able to make the necessary adjustments.

The increase of the 5-per-cent bath to 15 minutes resulted in about a 50-per-cent loss of the experimental animals. The chloride level was high at the end of the period of immersion, but well below the level of the 60-minute, 3-per-cent bath. The explanation is thought to be as previously described. Those fish remaining alive at the end of 48 hours were showing a reduction in salt level which, however, was still far above normal.

That the sodium chloride content of the blood of trout will increase during treatments with salt seems apparent. Whether this is due to the actual entrance of salt into the blood stream or an exchange of water cannot be stated. Krogh (1937, 1938, 1939) has demonstrated that if the chloride level is reduced below normal prior to immersion in a salt solution of a concentration well below that of the body fluids, an entrance of salt does occur. However, with normal fish, and a concentration of salt well above that of the body fluids, a change in salinity could well be due to an exchange of water. Since an edema was not apparent throughout these experiments, it is felt an exchange of water did play an important role.

It does appear that the rate of change of salinity of the blood is an important factor in the ability of the trout's body to stand salt treatments. The slower the change, the better the animal will withstand the treatment, even though the alteration of the chloride content of the blood is great. This is the possible explanation of the ability of fish to withstand the weaker concentrations of salt more readily than the stronger, since the stronger the solution the more rapid will be the change in the salinity of the blood.

In view of these results, it would be unwise to use a 5-per-cent salt bath for the treatment of fish, unless the period of immersion was quite short. Sick fish would probably be less able to withstand such treatments than the healthy fish used in these experiments. A 3-per-cent salt bath for periods up to 30 minutes would appear safe for normal fish. However, increasing the time of immersion to 60 minutes might not be desirable because of the prolonged effect on the blood chloride level. A 2.5-per-cent salt bath would be safe up to periods of 1 hour, depending on the health of the fish.

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Corporation of Rochester, New York, kindly furnished the special pipettes used in these experiments.

Conclusions

1. The salt content of the blood of trout was raised by feeding either 10, 15, 20 or 25 milligrams of salt per 5.6 gram fish.

2. The total amount of salt in the blood was far less than that retained by the fish, showing that the salt was distributed elsewhere in the trout's body.

3. The amount necessary to cause a rise in the blood chloride was found to be between 0.91 and 1.82 grams of salt per kilogram of body weight.

4. The ability of body of a fish to handle excessive amounts of salt is dependent upon the concentration in the intestinal tract. When the entrance of salt becomes too rapid, a rise in blood chloride results.

5. Salt absorbed is readily excreted at the lower levels. Large doses result in a great increase in blood chlorides, which requires a longer period after feeding to again reach a normal level.

6. The higher levels of salt produced an edema which caused no loss when 20 milligrams were fed, but did cause a mortality when the level was increased to 25 miligrams. The edema either disappeared or showed a tendency to do so as the rate of absorption decreased.

7. The amount of salt necessary to produce edema was found to be between 2.72 and 3.64 grams per kilogram of body weight.

8. The rate of absorption showed a curvilinear trend when plotted against time, a similar trend to that found for carbohydrates.

9. An increase in blood salt resulted when fish were treated with either a 3.0- or 5.0-per-cent salt bath. No increase resulted from treatment a 2.5-per-cent bath.

10. A 30-minute bath in 3.0-per-cent salt or a 10-minute bath in 5.0-per-cent salt caused a rise in blood salinity that quickly returned to normal after the fish were removed to fresh water.

11. A 60-minute bath in a 3.0-per-cent salt solution resulted in an extremely high chloride level of the blood that required about 48 hours to again return to normal.

12. A 15-minute bath in a 5.0-per-cent salt resulted in a loss of the majority of the fish. Those alive after 48 hours still had a high chloride level of the blood which was showing a tendency to reach a normal level.

13. The concentration of a salt bath determines the period of immersion. The greater the concentration, the faster the change in blood salinity and the fish is less able to make the proper adjustments. A long immersion period in a weaker solution may produce a higher chloride level of the blood without loss than a shorter period in a strong solution.

14. It is not certain whether the change in blood salinity is due to the entrance of salt or merely to an exchange of water.

15. These experiments do not answer the question of the benefits of salt treatments, but they do shed additional light upon the action of the salt.

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MORTALITY OF SMELT, *OSMERUS MORDAX* (MITCHILL), IN LAKES HURON AND MICHIGAN DURING THE FALL AND WINTER OF 1942-1943

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CONTENTS

Abstract 310
Introduction 311
Course of the mortality 313
Suggested causes of the mortality 316
Effect of the mortality on the smelt fishery 321
Development of the commercial fishery and production in Lake Michigan, 1931-1945 321
Composition of the commercial catch according to gear 324
Seasonal trends in the commercial fishery for smelt 324
Loss of production resulting from the mortality 331
Prospects for the recovery of the stocks of smelt 333
Improvement in the growth rate of smelt subsequent to the mortality 334
Literature cited 337

ABSTRACT

The mortality that nearly exterminated the huge stocks of smelt in Lakes Huron and Michigan during the fall and winter of 1942-1943 appears to have originated in central Lake Huron in the Saginaw Bay area in late September or early October 1942. The mortality spread rapidly northward reaching the Drummond Island area about the latter part of October and the St. Ignace region of the Straits of Mackinac near the end of the month. In the latter part of October smelt died also in the Canadian waters of Lake Huron including North Channel and Georgian Bay but exact details as to time and course are lacking. There is some evidence that the epidemic had not reached the Ontario shore of central Lake Huron by late May 1943. Spreading through northern Lake Michigan the mortality had penetrated as far south as Grand Traverse Bay by November 19 and as far west as Point Aux Barques, Michigan, by November 26, 1942. Smelt were reported to be dying in Lake Charlevoix, Michigan, in early February 1943, and in Green Bay toward the middle of that month. The mortality did not reach Crystal Lake where in contrast to Lake Charlevoix a dam barred the passage of fish from Lake Michigan. At the time of the 1943 spring spawning run (April) only a few scattered survivors remained from the vast populations.

After consideration of possible causes, it was concluded that the mortality could be explained only as resulting from a communicable disease (bacteria or virus). This explanation alone is in harmony with the following facts: the mortality was progressive, spreading from one area into adjacent areas over a period of at least 4½ months and under a great diversity of habitat conditions; only smelt were affected but within the species death overtook fish of all sizes from 2 inches on and all ages of both sexes, mature and immature; the mortality penetrated Lake Charlevoix where the passage of fish to and from Lake Michigan was possible but did not reach Crystal Lake where the passage from Lake Michigan was barred by a dam; the epidemic did not reach other inland lakes where

free and easy access from the Great Lakes was impossible nor did it extend to Lakes Superior, Erie, and Ontario.

Considered at first as a nuisance and a threat to the native fishes of the Great Lakes, the smelt ultimately became a fish of primary importance to commercial fishermen, sportsmen, and others. In Green Bay, the center of the commercial fishery, smelt became the dominant commercial species, yielding more than 4 million pounds in some years. Almost all of the commercial production was from nets set under the ice. The take by amateurs and others who dipped smelt from streams during the spawning run was even greater, amounting to as much as 5½ million pounds in a single year in the State of Michigan alone (the yield in Wisconsin may have been nearly as great).

The mortality of smelt was a severe blow to the nation's war-time food-production program. It is estimated that in 1943, in which year elaborate preparations had been made for the efficient utilization of the spawning-run production, the mortality reduced the output of smelt by about 13 million pounds. The total loss through the present (1946) season can be set in the neighborhood of 50 million pounds.

The first indication of a recovery of the smelt came in 1945 when a small amount was produced commercially in Green Bay and numerous light runs occurred in streams tributary to Lakes Huron and Michigan. The general level of abundance in 1945, however, is believed to have been less than 10 per cent of that of "pre-mortality" years. Such information as is available for 1946 suggests considerable further improvement in this year. Given good survival of young, it is anticipated that a large rise in the abundance of smelt can occur in 1947 and that by 1948 or 1949 the size of the populations should no longer be influenced by the number of spawners available in preceding years.

The smelt from the Escanaba area of Green Bay were without exception significantly longer and heavier in 1944 and 1945 than were fish of corresponding age captured in the same region in 1941. Furthermore, three of four comparisons indicated significantly greater size in 1945 than in 1944. This improvement in growth rate is believed to have been associated with the reduction in the smelt population brought about by the 1942-1943 mortality.

Introduction

No single event in the history of the Great Lakes fisheries has caught the popular fancy more completely or gained more widespread publicity than has the 1942-1943 mortality of the smelt in Lakes Huron and Michigan. Indeed from almost the very moment of its escape from Crystal Lake, Michigan, into Lake Michigan[1] this small fish seemed destined to remain more or less continually in the limelight. As the smelt first spread throughout the waters of the Great Lakes and multiplied with startling efficiency, it was bemoaned in loud voice and large type as an insufferable nuisance and a potential menace to the stocks of native fish. Some went so far as to predict the destruction of the Great Lakes fisheries, and many urged tnat measures be taken to control or, if possible, exterminate this new-comer.

[1]See Van Oosten (1937) and Dymond (1944) for information on the introduction, spread, and present distribution of the smelt in the Great Lakes area. Data on the biology of smelt and on the economics of the smelt fishery in this region may be found in papers by Creaser (1926, 1929), Langlois (1935), Schneberger (1937), Van Oosten (1940), and Beckman (1942). For a comprehensive general reference on smelts see Kendall (1927).

Fortunately, the gloomy predictions concerning the destruction of the Great Lakes fisheries by smelt did not materialize, although there is some evidence that suggests a relationship between the abundance of smelt in Green Bay and the numbers of lake herring, whitefish, and perhaps walleye pike in those waters. It was reported by fishermen that the young of these three species reappeared in the Bay in considerable quantities following the catastrophic mortality of the smelt in February 1943. An examination of the scales of the dominant size-groups of these young fish collected in 1944 and 1945 showed that all of them were hatched in the spring of 1943. The young herring taken May 25, 1945, ranged from 6.5 to 10.0 inches in length and averaged 8.1 inches (2.0 ounces); the whitefish collected October 9, 1944, ranged from 10 to 12½ inches; and the walleye pike caught June 5, 1945, varied from 11¼ to 13½ inches (6.8 to 14.0 ounces). That there is a causal relationship between the disappearance of the smelt in the spring of 1943 and the unusually good survival of lake herring, whitefish, and walleye pike in that same spring can not be asserted with full assurance although the coincidence of the two occurrences is highly suggestive. Since the smelt have not been found to feed on these three native species in Green Bay, the exact mechanism of their competitive relationships to the smelt is not clear; it may be food or it may simply be lack of space (overcrowding) or any one of several other factors.

Certain fisheries may even have profited by the presence of smelt. Lake trout, for example, accepted smelt readily as a new article of diet and thereby relieved the pressure to that extent on the chubs which hitherto had formed the main item of food. It is possible that this replacement in the diet of the trout may have been responsible to a large degree for the increase in the abundance of the chubs in both Lakes Huron and Michigan in 1943-1945. The relationship between the introduced smelt and the native species poses some interesting problems that require further study for their solution.

From the ecomonic point of view the smelt grew to be an asset of no mean importance in many Great Lakes communities. First came the smelt-dipping jamborees and the nationally advertised carnivals or festivals which brought a tourist trade in early spring —normally a closed season in the resort centers. Then came the shanty ice-fishing and smelt villages or "smeltaniae" which drew thousands of anglers to the North. Later the commerical fishermen of Green Bay (the area in which smelt probably reached their greatest abundance), who had complained most bitterly concerning the smelt nuisance, developed gear for the capture of the species under the ice in winter. As a result the commercial production of smelt soon exceeded that of other species in Green Bay, and many fishermen set their nets for smelt exclusively. Prices during the winter (a period of generally low production in the Great Lakes) were usually good, and the cold weather facilitated the handling of smelt, a fish that deteriorates rapidly.

The smelt had hardly more than established itself firmly as an important sport and commercial species when it was all but wiped out by the devastating mortality with which the present article is concerned. Not only was this mortality a severe blow to all who fished for smelt, whether for fun or food, but it came at an extraordinarily inconvenient time for the nation's war-time food-production program and for the fishery officials who were working so assiduously to augment the country's food stock through a more intensive exploitation of the species. During the winter of 1942-1943, the Fish and Wildlife Service in cooperation with members of the Michigan and Wisconsin Departments of Conservation developed an elaborate program for the utilization of smelt dipped during the spring spawning run, a period in which production ordinarily was limited stringently by market demand and many fish actually caught were wasted. Every possible step was taken to locate outlets for an expected take of 10 million pounds, and men were stationed at strategic points to expedite the orderly marketing of the catch. Unfortunately, however, vast numbers of smelt perished before the spawning season opened, leaving a highly publicized master plan of production but no fish.

Now that the most recent reports indicate the smelt to be well on the way toward a return to a high level of abundance in Lakes Huron and Michigan, it appears desirable to chronicle the events of this unusual mortality, to review the possible causes of the death of the smelt, and to evaluate the ecomonic loss to the fishery resulting therefrom.

Course of the Mortality

Information on the course of the mortality of smelt in Lakes Huron and Michigan has been obtained from a diversity of sources, a detailed listing of which does not seem necessary. It should be mentioned, however, that the bulk of the facts on which this section is based was collected or relayed to me by officials of the Michigan Department of Conservation. The excellent cooperation of that organization is gratefully acknowledged.

Many of the dates given here are of necessity approximate. When large quantities of dead fish are seen it is known merely that mortality has occurred. The date on which the first fish or the bulk of the fish have died must remain to a degree uncertain, although the condition of the bodies will give some clue as to the time of death. The smelt, an extremely soft-fleshed fish, decomposes rapidly in warm water. At near-freezing temperatures, however, the evidence afforded by the condition of the fish is less reliable; they may remain in a fair state of preservation for some time.

It should be emphasized also that the detection of mortality that has occurred may depend on meteorological-hydrological conditions and on the opportunity for observations. Reports of mortalities commonly are based on observations of dead fish that have been

washed ashore. If the prevailing winds and currents are such as to carry the fish away from shore few or none may be seen by persons frequenting the beaches. Furthermore, fish that have been washed ashore may escape notice in stormy or cold weather when relatively few people visit the beaches.

The extent of commercial fishing activities also has an important bearing on the detection of mortalities. In localities and at seasons of intensive operations commercial fishermen are almost certain to note and report any substantial mortality. In areas in which fishing is limited or during the off season, however, fishermen may not detect the presence of dead fish. In the winter, fishing activities are drastically reduced (largely suspended in shallow water) in those parts of Lakes Huron and Michigan that do not support an ice fishery.

It is believed that failure to learn of the presence of dead smelt accounts for the fact that no reports were received of mortalities in certain areas (notably the southern portions of Lakes Huron and Michigan) although the subsequent failure of runs indicated that the stocks were affected virtually throughout both lakes.

Despite certain weaknesses in our data traceable to circumstances just outlined, it is believed that the available facts are sufficiently complete and accurate to permit a satisfactory description of the course of the mortality of smelt.

According to our best information the mortality orginated in central Lake Huron. Large quantities of dead smelt were observed first in Michigan waters on October 3, 1942, at Black River by a Michigan conservation officer. Later investigations revealed that at that time dead smelt were numerous along the Michigan shore from Thunder Bay southward into Saginaw Bay to a point between East Tawas and Standish. They were also reported at that time to be "as thick as hay strewn on the water between Whitestone Point and Charity Island" in Saginaw Bay. The exact date on which smelt began to die is unknown. Although fishermen from Alpena, Michigan, stated that dead fish were not seen there before October 3, it is possible that the mortality set in at an earlier date toward the south. Neither is it known whether mortality occurred in parts of Saginaw Bay other than those mentioned above. The possibility that quantities of smelt may have died in Saginaw Bay only to be blown into the open lake is suggested by the fact that the wind was blowing out of the Bay almost continuously over the 8-day period, September 23-30, 1942 (from the southwest on every day but September 28 and from the northwest on that date).

From central Lake Huron the mortality spread rapidly northward. On October 12 great numbers of smelt, 2 to 4 inches in length, were seen floating in the water to the north of Alpena between Middle Island and Presque Isle. Dead smelt were first observed in the region of Drummond Island and Detour about the latter part of

October and in the Straits of Mackinac near the end of the month. Precise information is lacking on the course of the mortality in the Canadian waters of Lake Huron. It is known, however, that smelt died in Georgian Bay in October 1942, and newspaper accounts published in the North Channel area in early December 1942 referred to the mortality of smelt that apparently had occurred some time previously.

Information provided through the courtesy of the Fish and Wildlife Division of the Province of Ontario indicates that the mortality occurred throughout Georgian Bay and the North Channel and in northern Lake Huron south to Oliphant, Ontario. From the Sauble River south to Kincardine and probably to Goderich the smelt runs were reported to have been normal in the spring of 1943. In southern Lake Huron in the vicinity of Sarnia, Ontario, however, smelt failed to appear in their usual large numbers. Apparently the epidemic had not covered by the spring of 1943 the Ontario shore of Lake Huron as completely as the Michigan shore although it is probable that the mortality continued its progressive spread in Ontario in the summer of 1943. I have no information concerning the smelt runs in Canadian waters in 1944 and thereafter.

From Lake Huron the mortality moved through the Straits of Mackinac into Lake Michigan where dead smelt were reported at Charlevoix, Michigan, by November 24 and as far south as Norwood, Michigan, at the mouth of Grand Traverse Bay by November 19 and as far west as Point Aux Barques, only 19 miles above the most northerly passage into Green Bay, by November 26, 1942. The next mortality reported along the eastern shore of Lake Michigan occurred in Lake Charlevoix where the bottom was stated to be covered with dead smelt in early February 1943. It was in February also that the smelt mortality struck in Green Bay, no doubt the greatest center of abundance of the species in the Great Lakes and the locality with the major commercial fisheries for smelt.

The exact time at which smelt began to die in excessive numbers in Green Bay is not known; apparently the date varied in different areas of the Bay. Some fishermen stated that they had noticed quantities of dead fish as early as February 10-12. Others gave later dates, one fisherman reporting that smelt did not begin to die at Pensaukee, Wisconsin, until the first week in March. The Wisconsin records of the commercial catch of smelt indicate that the mortality reached northern Green Bay before March 1943, but did not affect production in southern Green Bay until some time in March. It was agreed rather generally, however, that the mortality began to affect the size of the lifts in Green Bay by or shortly after the middle of February and that once the decline had begun it proceeded at a rapid rate. This view, it will be seen in a later section on the Michigan fishery for smelt, finds support in the daily records of produc-

tion and of the catch per lift of pound nets (Table 4), the principal gear of capture for the species in Michigan waters.

If October 1, 1942, is taken as approximately the date the smelt began to die in central Lake Huron and the middle of February 1943, as the time of the first deaths in Green Bay, the estimate can be made that at least 4½ months were required for the mortality to reach all major centers of abundance of smelt in Lakes Huron and Michigan.

Suggested Causes of the Mortality

In the consideration of the possible causes of the mortality of smelt I had the benefit of numerous suggestions from fellow-scientists and from interested members of the general public who wrote to me from localities stretching from the Atlantic to the Pacific Ocean and from Canada to the Gulf of Mexico. Certain of these suggestions were extremely helpful; others were at least highly interesting. All will be reviewed in the discussion that follows.

The evaluation of suggested causes of the mortality of smelt is simplified greatly when it is kept constantly in mind that no explanation can be accepted that is inconsistent with any one of the following established facts:

1. The smelt was the only species affected. Dead fish of other species were observed only in normal numbers.

2. All sizes from at least 2 inches on and all ages of smelt of both sexes, mature and immature, were involved. These facts were determined through studies of the age, size, and sex composition of samples of dead or dying fish.

3. The mortality was progressive, moving from a particular area into adjacent areas and continuing to spread over a period of at least 4½ months (October-February). Deaths occurred in the open lakes, in bays, in channels, in tributary waters, and in open water as well as under the ice. Thus the mortality took place under a great diversity of habitat conditions as well as over a long period of time.

4. Whereas the wholesale mortality penetrated a connecting inland lake (Lake Charlevoix) where the smelt had free access from and to Lake Michigan, no deaths occurred in abnormal numbers in Crystal Lake (Michigan) where passage from Lake Michigan was blocked by a dam. Neither did the epidemic reach any other inland lake where free and easy access from the Great Lakes was impossible, nor did it extend to Lakes Superior, Erie, and Ontario.

The listing that follows may not include all conceivable possible causes of the mortality of smelt. It is believed, however, to cover all explanations with any substantial degree of credibility, not to mention some that are not quite so credible. Brief comments are given as to the acceptability of each of these suggestions:

1. *Sabotage by Japanese agents.*—This hypothesis must be rejected pending receipt of information on the *modus operandi* of the sabo-

teurs and an explanation of the reasons for the selection of the unhappy smelt rather than defense installations as the victim of an elaborate plot.

2. *Bombing and gunfire.*—No firing of heavy guns occurred on or along Lakes Huron and Michigan during the war and such practice bombs as were dropped into the lakes carried extremely light charges. Furthermore, bombing and firing practice were confined to highly restricted areas that included very little of the region in which the heaviest mortalities were observed. Finally, examination of the dead smelt by Dr. Leonard N. Allison, pathologist of the Michigan Department of Conservation, failed to reveal any injuries of the type (ruptured swim bladder, crushed liver) to be expected from concussion.

3. *Supersonic vibrations (increased use of radar and radio-direction beams; ultra-high-frequency experiments) causing a derangement of the nervous system.*—Even if we were to grant that the various "vibrations" mentioned can have a direct adverse effect on fish life over so large an area as Lakes Huron and Michigan the questions remain as to why the smelt alone suffered nervous derangement and as to why the supposedly super-sensitive smelt should be spared in Crystal Lake (also in other inland lakes and in Great Lakes waters outside Lakes Huron and Michigan) but destroyed in Lakes Huron and Michigan and in Lake Charlevoix.

4. *Earthquake.*—Seismic disturbances of sufficient violence and persistence to account for the mortality unquestionably would have left us with greater worries than those occasioned by the loss of the smelt.

5. *Electric and wind storms.*—The deaths of the smelt were not associated with storms, particularly the mortalities that occurred under the ice.

6. *"Bad" water (pollution; oxygen deficiency; turbidity; discharge of lethal poisons into the water in the course of experiments in chemical warfare; addition of lethal chemicals leached from surrounding territory during periods of high water; deficiency in some vital mineral or organic substance).*—Pollution in the Great Lakes may be responsible for the death of fish in limited areas but not over all of the large expanse covered by the smelt mortality. Oxygen deficiency is unknown in Great Lakes waters, with the exception of small, heavily polluted areas, and tests of water from beneath the ice in Green Bay in the winter of 1943 revealed an abundance of dissolved oxygen. Further, no congestion of the blood in the heart and arteries, such as often occurs in fish killed by pollution, could be discovered by Dr. Allison. Turbidity could not have caused the observed widespread mortality because the waters of Lakes Huron and Michigan are known to be very clear except at certain times in local areas near shore and after heavy storms. As indicated previously the deaths were not associated with storms. The discharge of poisonous materials into the water could account for the death of fishes at or near the sources of

the pollution but it is difficult to believe that such lethal materials were dumped in sufficient quantities to kill smelt throughout Lakes Huron and Michigan and in such a manner as to poison the waters systematically over a period of months. Furthermore, it is hardly to be expected that smelt alone would be affected. The leaching of chemicals from the surrounding territory in amounts sufficient to poison smelt throughout Lakes Huron and Michigan would necessitate the assumption of unreasonably large concentrations of toxic materials in the soil. The suggestion of a deficiency of some vital chemical from tributary streams or elsewhere carries with it the implication that this material was exhausted over an expansive area and in a progressive manner. In fact, any explanation of the mortality on the basis of changes in the nature of the water is handicapped by the necessity for assuming that the change occurred progressively as regards time and locality and in a wide variety of habitats. Then, too, why was the smelt alone affected and why did the water change in Lake Charlevoix but not in Crystal Lake?

7. *High water.*—Although the water levels of the Great Lakes have risen in recent years, this change can not account for the movement of the mortality from one area to another in a single lake over an extended period of time.

8. *Heavy formation of ice (said to have "smothered" the smelt).*—The mortality began and had spread through much of Lakes Huron and Michigan before ice was formed. As stated above, tests of water from beneath the ice in Green Bay proved dissolved oxygen to be plentiful.

9. *Low temperatures.*—The main body of Lake Michigan is reported to have become homothermous in the winter of 1942-1943 at a temperature about 4°F. lower than is usual. Smelt began to die, however, while the water was still relatively warm and continued to die through a considerable range of temperatures. It is likewise inconceivable that an upwelling of cold water from the depths or the movement of this water inshore, such as has been held responsible for the sudden widespread mortality of certain marine fishes, could account for the deaths of the smelt. Such an upwelling or movement would be physically impossible during the winter or under the ice when the water had reached a homothermous condition.

10. *High temperatures.*—The smelt died in the fall and winter when water temperatures could not have been high.

11. *Inability of a fish of marine origin to adapt itself to permanent habitation in fresh water.*—The belief expressed by some that after a certain number of years in fresh water smelt suffer a "loss of vitality" or undergo a "softening of the bones" does not take into account the existence of numerous natural land-locked populations. Smelt introduced into the Great Lakes area came from land-locked stocks. It may be mentioned also that the examination of dead smelt failed to reveal a softening of the bones. Then, too, why did the smelt

not die in Crystal Lake, the original source of the Lake Huron and Lake Michigan fish?

12. *Failure of year classes to survive in several successive years.*—This explanation is obviously untenable since the mortality struck all age groups at the same time; the disappearance of the smelt was not a gradual process covering several years.

13. *Starvation.*—As indicated in item 20 (p. 320) some of the dead or dying smelt had the remains of food in their intestines and none that were examined showed any evidence of starvation.

14. *Death, through senescence, of the older individuals of a dense population of a short-lived fish.*—Fish of all ages, including young of the year, suffered mortality. In some samples of the dead smelt as many as 80 per cent of the fish were young of the year.

15. *Physiological changes associated with reproduction.*—It is true that considerable mortality commonly occurs among smelt following spawning. Such mortalities usually take place in May (see p. 321). However, the mortality that almost exterminated the stocks in Lakes Huron and Michigan did not begin until 5 and 6 months after the 1942 spawning and apparently was ended before the 1943 spawning. Furthermore, the mortality afflicted both mature and immature fish, males and females.

16. *Overcrowding.*—The phenomenon of pronounced cycles in which populations build up to an extremely high level only to be reduced drastically by sudden heavy mortality (including even mass suicide) is well known. Numerous theories have been advanced in explanation of these cycles. A criticism of them is, of course, beyond the scope of this paper. With specific reference to the smelt, it may be stated that the density of the population was high at the time the mortality struck. Evidence from commercial fishery statistics to be presented in a later section (Table 3) indicates that, in the State of Michigan waters of Green Bay at least, the abundance in January 1943, just before the mortality, was far above the 1939-1942 average for this month and was greater than that in January of any earlier year of the period. If we assume, however, that the population density of smelt in Lakes Huron and Michigan had reached the "exploding point" a troublesome question still exists as to the actual mechanism of the mortality. Did the smelt die from a too great concentration of some material that they themselves added to the water; did they perish from the lack of some vital substance of which they depleted the water (*cf.* paragraph 5 above); or did overcrowding *per se* induce nervous disorders to which the fish succumbed? Any explanation based on overpopulation faces the handicap of having to account for the progressive behavior of the mortality, previously described, and for the failure of deaths to occur in excessive numbers in Crystal Lake as well as in Lake Charlevoix.

17. *Migration.*—Any migration theory ignores completely the ob-

served fact of the mortality as well as the disappearance of smelt in all areas of Lakes Huron and Michigan.

18. *Destruction by marine lamprey.*—The dead smelt bore no lamprey marks. It is doubtful also whether a 15- to 30-inch lamprey can surmount the mechanical difficulties involved in attaching itself to a 2- to 10-inch smelt.

19. *Parasites.*—Samples of the dead smelt were examined by Dr. Leonard N. Allison who reported, "A few parasites were found in some of the smelt but none were present in sufficient numbers to have caused the death of the fish."

20. *Infectious disease (bacteria; virus).*—The gross examination of the dead smelt by Dr. Allison gave no indication of disease, or for that matter of any abnormal condition whatsoever. Not only were the fish free from any kind of lesions or visible injury, but the organs as well as the fish had a normal, healthy appearance. Furthermore, the presence of food in the intestines proved that the smelt had been feeding actively until shortly before their death—they apparently were not seriously ill nor were they starved. In spite of the complete lack of direct evidence for an infectious disease, however, death from that cause offers by far the most likely explanation of the mortality. A communicable ailment specific to the smelt is the only explanation that does not conflict in some way with the "established facts" set forth early in this section. The circumstance that smelt of every size were affected, the nature of the spread of the mortality, and the failure of smelt to die, at least in large numbers, in Crystal Lake all can be explained best on the assumption that the mortality was caused by a disease. It is concluded therefore that the smelt was the victim of an epidemic.

I have been asked repeatedly by correspondents whether a catastrophe similar to the one of 1942-1943 has ever been recorded for the smelt in other regions or in earlier years. Probably the earliest account of such a mortality of epidemic proportions was published by the Plattsburgh (N. Y.) Republican, when it reported the sudden, simultaneous deaths of thousands of these fish on Lake Champlain during the summer of 1882 (Kendall, 1927). The catastrophe was associated with an extraordinary display of the aurora borealis and an accompanying electric storm of severe intensity. It was suggested that perhaps Nature's electric battery was the cause of death. A recurrence of a disastrous mortality was reported on the same lake in May 1883. This time the deaths were attributed to windstorms, the unfortunate smelt of the inshore waters having been blown ashore with the churning driftwood. It was stated that such "windstorm" mortalities were frequent in the earlier years. Since these years no further records were found by Kendall of mortalities of smelt that reached epidemic proportions, although from time to time minor casualties were observed, mostly in the spring and fall, in the eastern lakes where the smelt are native.

On the Great Lakes heavy mortalities have been reported only since 1939 in Little Bay de Noc on Green Bay, although minor casualties have occurred in other regions and in earlier years. All of these mortalities, however, have occurred in the spring, usually May, and seemed to have been associated with spawning or at least with the fishing activities during the spawning run. A widely accepted theory is that death was caused by a fungus (Saprolegnia) brought on by bruises that resulted from the crowding in spawning runs and from dipping. However, this theory is unacceptable for the following reasons: (1) Examination by Dr. L. N. Allison of a sample of 29 dying smelt in April 1941, revealed few bruised areas under the fungus patches and no external parasites; (2) some of the fish were practically free from fungus or had such a light attack that this organism could not have been the cause of death; and (3) three of the fish had not yet spawned and presumably had not been subjected to the crowding or dipping. Then, too, the theory does not explain why spring dipping or spawning resulted in heavy mortalities in Little Bay de Noc but not in other areas with equally dense populations, and why the mortalities occurred in successive years subsequent to 1938 but not previous to this time when dense spawning runs and dipping also took place. Further, Michigan investigators reported that the smelt beached on the shores of Little Bay de Noc in May 1941, ranged from 3 to 10 inches in length. Undoubtedly the smaller individuals were still immature and had not taken part in the spawning runs. The cause of the wholesale deaths in May, then, remains obscure especially in view of the fact that the fish appeared to be normal in all respects, both internally and externally.

Effect of the Mortality on the Smelt Fishery

Development of the commercial fishery and production in Lake Michigan, 1931-1945.—The commercial fishery in the Great Lakes for the introduced smelt has always centered in Green Bay, Lake Michigan. The only smelt fishery of even minor importance was developed in the extreme northeastern corner of Lake Michigan, and here the production has always been low (maximum yield of 44,000 pounds in 1941). No commercial production of smelt has been reported for Lake Erie[2] or for Lake Ontario (the species was found in Lake Ontario before it could have been introduced from the other Great Lakes). The recorded catches from Lakes Superior and Huron have been insignificantly small and mostly taken incidentally in fisheries prosecuted for other species.

Although the smelt in its spread through the Great Lakes is known to have reached Green Bay by 1924, the first records of commercial production are for 1931. In that year 400 pounds were taken in the

[2]This statement applies through 1944. I have been informed that in the spring of 1945 a Canadian firm took a relatively large quantity of smelt from Lake Erie (daily lifts from all nets as high as 400 pounds). I was informed further that in 1946 that firm set one pound net specifically constructed for the taking of smelt.

State of Michigan waters of Lake Michigan and 86,000 pounds in Wisconsin waters (Table 1). In Wisconsin, where the fishery developed first, the output of smelt was slightly lower in 1932 (76,000 pounds) than in 1931, but increased tremendously to 900,000 pounds in 1933 and exceeded a million pounds in 1934. Following a drop to 790,000 pounds in 1935, the Wisconsin production exhibited an upward trend that culminated in yields of more than 1¾ million pounds in 1940 and 1941. A decrease from 1,755,000 pounds in 1941 to 1,124,000 pounds in 1942 was followed by another drop to 502,000 pounds in 1943, the year of the general mortality. In 1944, the yield was only 4,300 pounds.

The development of the smelt fishery in Lake Michigan progressed much more slowly in Michigan than in Wisconsin waters. The production first exceeded 100,000 pounds in 1936 and was not above a half-million pounds until 1938. The catch rose sharply, however, from a little more than 600,000 pounds in 1939 to more than 3 million pounds in 1941. From this peak the output declined to 2,229,000 pounds in 1942 and, as was true also in Wisconsin, underwent a further decrease (to 1,723,000 pounds) in 1943. In 1944 and 1945, the yields were insignificantly small (198 and 43,500 pounds). It will be noted that despite later development the Michigan smelt fishery ultimately became the more productive. The Michigan catch was considerably greater than that in Wisconsin in each year of the period, 1940-1943.

In Lake Michigan as a whole the commercial output of smelt rose sharply from a level of less than 100,000 pounds in 1931 and 1932 to 909,000 pounds in 1933. A further increase to 1,031,000 pounds in 1934 was followed by a decline to 835,000 pounds in 1935. Thereafter the production increased annually to a maximum of 4,775,000 pounds in 1941. Decreases of more than a million pounds occurred in both 1942 and 1943. In 1944, the smelt fishery virtually disappeared (4,500 pounds) and in 1945 it showed a small recovery (Michigan catch, 43,500 pounds).

From the totals at the bottom of Table 1 it may be seen that from the first year of recorded commercial exploitation (1931) up to the time of the general mortality (in 1943) that reduced the stock almost to the point of extinction the commercial fishermen of Lake Michigan took approximately 24 million pounds of smelt. Roughly 54 per cent of this total was taken in Wisconsin and 46 per cent in Michigan waters. In Green Bay, which yielded virtually all of the catch, the smelt became the dominant commercial species.

The annual yields listed in Table 1 represent only a fraction of the total take of smelt. In addition to the strictly commercial winter fishery with nets there were the shanty ice-fishing and other hook and line fishing as well as the spring spawning-run fishery in which smelt were dipped in prodigious numbers from streams tributary to the lakes. A considerable portion of the spring catch, however, found its way into commercial channels—enough, at least, to bring about a

[Production in pounds, round weight. Percentages are shown in parentheses.]

Year	Production in Wisconsin				Production in Michigan				Production in entire lake
	Gill nets[1]	Pound nets	Other[2]	Total	Small-mesh gill nets[3]	Pound nets	Other[4]	Total	
1931	84,469	.....	1,600	86,069	.....	.....	400	400	86,469
	(98.1)	.....	(1.9)	.....	.....	.....	(100.0)	.....	.....
1932	40,643	20,666	14,494	75,803	.....	.....	22,606	22,606	98,409
	(53.6)	(27.3)	(19.1)	.....	.....	.....	(100.0)	.....	.....
1933	.....	.....	.....	900,000	7,335	.....	1,961	9,296	909,296
	.....	.....	.....	.....	(78.9)	.....	(21.1)		.....
1934	264,000	603,500	146,200	1,013,700	3,250	3,895	9,760	16,905	1,030,605
	(26.1)	(59.5)	(14.4)		(19.2)	(23.1)	(57.7)	.....	.....
1935	.....	.....	.....	790,300	.....	28,166	16,375	44,541	834,841
	.....	.....	.....	.....	.....	(63.2)	(36.8)	.....	.....
1936	565,200	402,300	114,400	1,081,900	.....	89,053	31,033	120,086	1,201,986
	(52.2)	(37.2)	(10.6)	.....	.....	(74.2)	(25.8)	.....	.....
1937	876,500	338,800	16,000	1,231,300	20,000	136,606	39,513	196,119	[5]1,427,519
	(71.2)	(27.5)	(1.3)	.....	(10.1)	(69.7)	(20.2)	.....	.....
1938	1,041,900	88,500	42,100	1,172,500	222,540	405,799	52,833	681,172	1,853,672
	(88.9)	(7.5)	(3.6)	.....	(32.7)	(59.6)	(7.7)	.....	.....
1939	1,029,600	341,300	7,800	1,378,700	191,139	370,926	41,585	612,650	1,991,350
	(74.7)	(24.7)	(0.6)	.....	(31.2)	(62.0)	(6.8)	.....	.....
1940	1,181,000	609,100	.....	1,790,100	454,105	1,924,971	39,609	2,418,685	4,208,785
	(66.0)	(34.0)	.....	.....	(18.8)	(79.6)	(1.6)	.....	.....
1941	1,395,400	359,600	.....	1,755,000	450,214	2,520,015	49,314	3,019,543	4,774,543
	(79.5)	(20.5)	.....	.....	(14.9)	(83.5)	(1.6)	.....	.....
1942	859,800	264,100	.....	1,123,900	161,125	2,030,075	37,447	2,228,647	3,352,547
	(76.5)	(23.5)	.....	.....	(7.2)	(91.1)	(1.7)	.....	.....
1943	169,000	325,800	7,200	502,000	91,794	1,611,940	19,697	1,723,431	2,225,431
	(33.7)	(64.9)	(1.4)	.....	(5.3)	(93.5)	(1.2)	.....	.....
1944	.....	.....	.....	4,344	.....	154	44	198	4,542
	.....	.....	.....	.....	.....	(77.8)	(22.2)	.....	.....
[6]1945	.....	.....	.....	.....	.....	40,303	3,180	43,483	.....
	.....	.....	.....	.....	.....	(92.7)	(7.3)	.....	.....
Total (1931-1943)	[7]8,175,564	[7]4,126,376	[7]599,332	12,901,272	1,601,502	9,130,446	362,133	11,094,081	[5]23,995,453
Percentage	(63.4)	(32.0)	(4.6)	.....	(14.4)	(82.3)	(3.3)	.....	.....

[1]Includes catch from gill nets of all mesh sizes; bulk of production, however, from small-mesh nets (principally 1½ to 1⅝ inches, extension measure).
[2]Includes catches of fyke nets and haul seines.
[3]Mesh sizes ranged from 1½ to 1⅝ inches, extension measure.
[4]Includes catch of gill nets of 2¼-inch mesh and larger, trap nets, fyke nets, and dip nets (only when reported under commercial licenses), and also small quantities of smelt for which records of gear were lacking.
[5]Includes 100 pounds reported from Indiana in 1937; total excludes 1944 catch.
[6]Data not yet available for Wisconsin in 1945.
[7]Estimated on assumption that percentages in 1932 and 1935 were the same as for the years immediately preceding and following.

complete collapse of prices each season. Although exact figures could not be obtained on the catch of smelt by dippers, they undoubtedly took a greater quantity during the short spawning run than commercial fishermen produced during the entire winter season. The Michigan Department of Conservation, for example, estimated that dippers took more than 5½ million pounds from the State of Michigan waters alone in 1942. The spring catch in Wisconsin waters may have been nearly as large.

Composition of the commercial catch according to gear.—Small-mesh gill nets and pound nets accounted for the bulk of the 1931-1943 production of smelt in Lake Michigan (Table 1). Gill nets were the more important in Wisconsin waters where on the average they took 63.4 per cent of the 1931-1943 catch (this percentage actually includes an insignificant quantity taken in large-mesh nets) as compared with 32.0 per cent in pound nets. In Michigan waters, on the contrary, pound nets yielded the bulk (82.3 per cent) of the 1931-1943 catch whereas small-mesh gill nets produced only 14.4 per cent of the total. The annual fluctuations in the percentages of the total production contributed by the principal gears were rather wide and largely without trend in Wisconsin waters. Gill nets contributed more than half the total in every year for which data are available except 1934 and 1943 when pound nets were the dominant gear. In the earlier years (1931-1937) of the smelt fishery in Michigan waters the percentage of the total catch taken in small-mesh gill nets ranged from 10.1 in 1937 to 78.9 in 1933 (no production by this gear in 1931, 1932, 1935, and 1936); for pound nets the percentage ranged from 23.1 in 1934 to 74.2 in 1936 (no production by pound nets in 1931, 1932, and 1933). During the later years (1938 through 1943) when the fishery was well established the relative importance of small-mesh gill nets declined consistently (decrease in percentage from 32.7 in 1938 to 5.3 in 1943) while that of pound nets increased (rise in percentage from 59.6 in 1938 to 93.5 in 1943). The small 1945 catch in Michigan waters was also taken mostly in pound nets (92.7 per cent). In both states the percentage of the total output of smelt taken in "other" gears was highest in the early years when the fishery was in the process of development.

The small-mesh gill nets fished for smelt were essentially the same as the "bait net" that had long been employed to capture small chubs for use as bait in the set-hook fishery for lake trout. The pound nets as fished for smelt were to a large extent a new development in that they were constructed of webbing of unprecedentedly small mesh size (mostly 1½ inches, stretched measure, as manufactured) and were held in position, not by the customary stakes, but rather by being frozen in the ice.

Seasonal trends in the commercial fishery for smelt.—The nature of the seasonal trends in the commercial production of smelt is indicated by tabulations (based on records prepared in the Ann

TABLE 2.—*Production of smelt (pounds) according to month in the State of Michigan waters of Green Bay, 1938-1945*

[Monthly percentages are shown in parentheses]

Month	Production in year								Average (1938-1942)
	1938	1939	1940	1941	1942	1943	1944	1945	
January	99,350 (14.8)	33,066 (5.5)	79,929 (3.3)	211,823 (7.1)	133,789 (6.0)	914,546 (53.1)	3	1,134 (2.6)	111,591 (6.3)
February	198,921 (29.6)	76,682 (12.6)	774,717 (32.4)	1,079,326 (36.3)	732,163 (33.1)	766,569 (44.5)	7	6,319 (14.7)	572,362 (32.3)
March	316,371 (47.1)	399,284 (65.7)	1,357,361 (56.8)	1,633,011 (54.9)	1,275,502 (57.7)	42,313 (2.4)	....	12,021 (27.9)	996,306 (56.2)
April	21,864 (3.3)	91,201 (15.0)	145,522 (6.1)	45,918 (1.5)	63,735 (2.9)	..... (0.0)	7	4,928 (11.4)	73,648 (4.2)
Others	35,185 (5.2)	7,233 (1.2)	34,565 (1.4)	5,750 (0.2)	6,758 (0.3)	..... (0.0)	14	18,721 (43.4)	17,898 (1.0)
Total	671,691	607,466	2,392,094	2,975,828	2,211,947	1,723,428	31	43,123	1,771,805

Arbor office of the Fish and Wildlife Service) of the catch by month or months in the State of Michigan waters of Green Bay during the period, 1938-1945 (Table 2). Particular attention should be given the figures for 1938-1942 since the 1943 mortality disrupted completely the normal course of the fishery in that year and few smelt were taken in 1944 and 1945. It is evident that the smelt fishery was prosecuted chiefly during the winter months. During the period, 1938-1942, 99.0 per cent of the total catch was taken in January-April (most of the April production through the ice early in the month) and in only one year (1938) did the percentage captured in these four months fall below 98.6. Without exception during these years the monthly catch increased from January to March and then fell away sharply in April. March, the most productive month, yielded from 47.1 to 65.7 per cent of the output in the individual years and contributed 56.2 per cent of the 1938-1942 total. February ranked second (32.3 per cent of the 1938-1942 total), with January third (6.3 per cent) and April fourth (4.2 per cent). The extent of fishing operations in January and April was influenced each year by ice conditions (solid ice is necessary for "winter" fishing), thus shifting the relative importance of these two months (compare, for example, 1938 and 1939).

The monthly distribution of the catch in 1943 was abnormal in that (1) the January production was extraordinarily high (more than four times that in 1941 which had the highest January yield reported for any previous year), (2) the trend of production was downward rather than upward in February and March, and (3) no production at all was reported for April or any subsequent month. It will be brought out later that the large catch in January was chiefly the result of the unusual abundance of fish (Table 3) whereas the downward trend in February and March and the absence of any yield in April and later months can be attributed to the reduced catch per lift resulting from the mortality (Table 4). In 1945, the percentage of the total taken after April (43.4 per cent) was far greater than that in any of the years, 1938-1942. The production of smelt during the summer and fall of 1945 can be attributed to the intensity of the pound-net fishery for the lake herring which was far more abundant in 1945 than in any of the immediately preceding years.

Records of the monthly trends in the catch of smelt per unit of fishing effort in the State of Michigan waters are available (Table 3) for the two principal gears, small-mesh gill nets and pound nets, for 5 years of the 6-year period, 1939-1945 (almost no production in 1944). Here, as was true with the statistics on production, attention must be focused first on the data for the years preceding 1943 in order to gain an idea of normal conditions. It is obvious that the catch of smelt per unit of fishing effort ordinarily increases continuously from January through April. Only one exception can be found

TABLE 3.—*Catch of smelt (pounds) per lift of 1,000 linear feet of small-mesh gill nets and of one pound net in the State of Michigan waters of Green Bay during the months of January-April, 1939-1945*

[The averages at the bottom of the table are unweighted. No data for 1944 in which year production was almost nil]

Year	Small-mesh gill nets				Pound nets			
	January	February	March	April	January	February	March	April
1939	50	76	128	223	267	207	474	1,173
1940	45	60	74	110	347	365	544	1,252
1941	68	59	95	233	353	378	472	[1]391
1942	....	57	88	....	225	313	447	869
1943	67	62	37	....	374	211	34	....
1945	....	....	....	....	13	23	50	68
Average, 1939-1942	54	63	96	189	298	316	484	921
Percentage of January average	100	117	178	350	100	106	162	309

[1]Based on only 27 lifts; 1939-1942 mean exclusive of this figure is 1,098 and this average expressed as a percentage of the January mean is 368.

to this trend in the data for the gill nets (February 1941) and two for pound nets (February 1939 and April 1941—relatively little fishing in the latter month). The monthly trends in the catch per unit of effort possibly can be described best by the figures at the bottom of the table in which the average yield for each month is expressed as a percentage of the January mean. Here it may be seen that with the January figure set at 100 per cent the catch of smelt per 1,000 linear feet of small-mesh gill nets lifted was 117 per cent in February, 178 per cent in March, and 350 per cent in April. For the pound nets the percentages were: February, 106; March, 162; and April, 309 (368 if the data for April 1941 are excluded—see footnote to Table 3). The trends for the two gears are closely similar.

In 1943, the changes from month to month in the catch of smelt per unit of fishing effort were precisely the reverse of the normal trend, for the average lifts decreased in both February and March. The returns per unit of effort were extremely small in the latter month. The catch of 37 pounds of smelt per 1,000 feet of gill nets was only 39 per cent of the 1939-1942 average of 96 pounds for March and the yield of 34 pounds per lift of one pound net was only 7 per cent of the average for that gear.

The figures for the catch per unit of effort in January 1943, verify the earlier statement that the high production in that month was the result principally of increased abundance. The yield of 67 pounds per 1,000-foot lift of small-mesh gill nets was above the 1939-1942 average of 54 pounds but was slightly less than the 1941 figure of 68 pounds. In the pound nets the mean catch of 374 pounds per lift in January 1943, the highest recorded for that month, was considerably above the 1939-1942 average of 298 pounds and was also the averages for 1940 (347 pounds) and 1941 (353 pounds), the next best years.

The records of the catch per lift in 1945 prove that in spite of some recovery the density of the population was still extremely low. The

averages for the individual months were only 10 per cent or less of the corresponding 1939-1942 means.

In an attempt to determine more exactly the time at which the mortality of smelt began in Green Bay and to trace the effects of that mortality during the fishing season, the monthly reports submitted by the State of Michigan fishermen operating pound nets (the principal gear for the capture of smelt in Michigan waters—see Table 1) in that area for January, February, and March 1943, were analyzed to bring out the daily fluctuations in the catch per lift (Table 4 and Figure 1). Table 4 contains also a record of the production and the number of pound nets lifted each day.

The catch per lift, which may be taken as an approximate measure of the abundance of fish on the grounds (and to some extent of their activity as the pound net is a stationary gear and consequently dependent on the movements of the fish for its effectiveness), rose sharply in early January, stood at high level about 10 days (January 4-13), and thereafter was relatively steady up to about the middle of February. At this time, however, a decline set in. The catch per lift dropped below 200 pounds for the first time during the winter fishery on February 18, was less than 100 pounds on February 24 (consistently below 100 following February 27), and exceeded 50 pounds only once (March 26—only four lifts) after March 5. These reduced catches in the latter part of the season, it must be emphasized, are directly contrary to the normal course of the fishery as described previously. The general trend of the changes in the catch per lift in 1943 probably can be brought out more effectively by the following tabulation in which the three months have been divided into seven periods:

Period	*Number of days*	*Pounds of smelt per lift*
January 1-3	3	307
January 4-13	10	596
January 14-February 17	35	276
February 18-23	6	155
February 24-March 1	6	88
March 2-8	7	42
March 9-31	23	21

It may be seen from the above figures that, if we ignore the unusually large catches of January 4-13, the major reduction in the catch per lift occurred between February 17 and March 2 or in a period of less than two weeks. Several valid reasons exist for refusing to accept the drop from the large lifts of January 4-13 as the result of mortality of smelt. First, and most important, no mortality was reported at that time by fishermen of the area who certainly would have observed dead fish in quantities sufficiently great to account for the decline in the catch per lift that occurred between January 13 and January 15. Futhermore, the large lifts of January 4-13 were not only abnormally high for that month (*cf.* Table 3) but also were

TABLE 4.—*Daily production of smelt, number of lifts, and catch per lift of pound nets in the State of Michigan waters of Green Bay, January-March, 1943*

[The figures on production are exclusive of the following catches of pound nets for which records were lacking of the number of net lifts: January, 28,367 pounds; February, 998 pounds; March, 374 pounds]

Day of month	January			February			March		
	Production (pounds)	Number of lifts	Catch per lift (pounds)	Production (pounds)	Number of lifts	Catch per lift (pounds)	Production (pounds)	Number of lifts	Catch per lift (pounds)
1	2,612	10	261	25,275	113	224	5,825	85	69
2	5,400	17	318	32,789	132	248	2,955	62	48
3	9,583	28	342	24,345	100	243	2,652	57	47
4	15,927	30	531	32,587	125	261	2,207	42	53
5	29,570	44	672	43,865	129	340	4,261	82	52
6	28,368	49	579	31,702	116	273	832	42	20
7	29,231	50	585	37,534	120	313	641	21	31
8	36,459	63	579	45,483	140	325	2,603	63	41
9	29,328	59	497	32,489	131	248	616	24	26
10	40,670	63	646	24,948	123	203	1,289	56	23
11	52,662	74	712	17,592	82	215	1,124	50	22
12	53,657	85	631	45,779	129	355	1,218	47	26
13	41,781	79	529	12,272	61	201	593	42	14
14	30,244	84	360	25,764	100	258	320	14	23
15	20,743	89	233	34,922	124	282	229	12	19
16	26,353	98	269	26,014	123	211	887	53	17
17	21,434	85	252	28,462	121	235	296	16	18
18	16,498	60	275	25,859	136	190	371	27	14
19	8,595	34	253	18,686	118	158	403	22	18
20	28,525	87	328	20,806	146	143	259	8	32
21	6,247	24	268	16,948	124	137	185	20	9
22	28,374	99	287	26,220	140	187	645	29	22
23	30,185	107	282	15,583	137	114	383	21	18
24	31,825	99	321	12,258	126	97	666	19	35
25	36,844	110	335	8,538	101	85	113	8	14
26	37,305	108	345	7,768	76	102	233	4	58
27	39,563	128	309	14,336	134	107	210	10	21
28	29,208	115	254	5,422	83	65	62	5	12
29	35,698	104	343	.....	.....	.....	40	3	13
30	24,574	107	230	.....	.....	.....	14	5	3
31	28,064	97	289	.....	.....	.....	116	5	23
Total or average	855,707	2,286	374	694,246	3,290	211	32,248	954	34

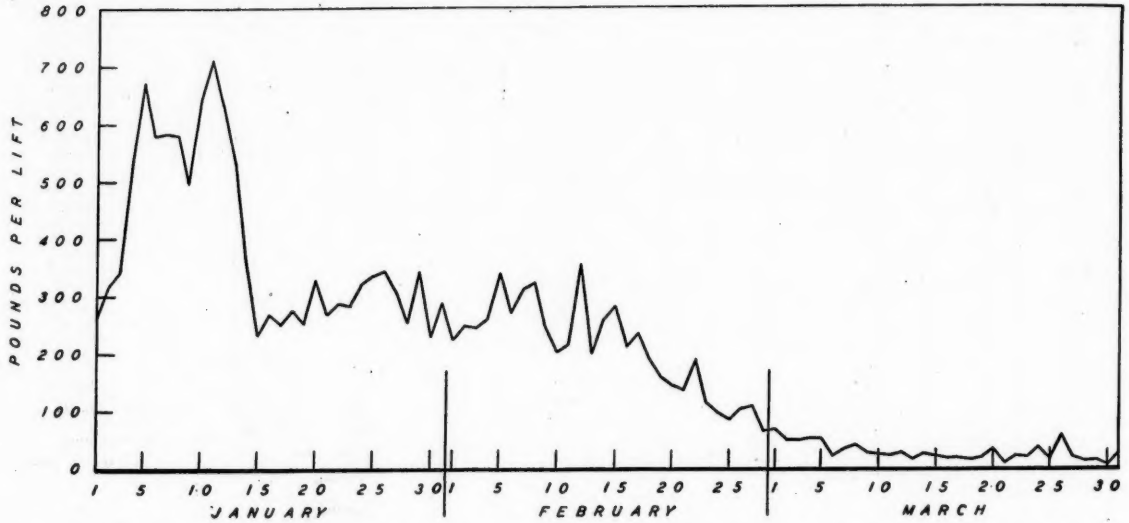

FIGURE 1.—Daily fluctuations in the catch (pounds) of smelt per lift of pound nets in the State of Michigan waters of Green Bay, January-March 1943

preceded by much smaller catches on January 1-3 and followed by a period of more than a month during which the catch per net remained relatively stable at a much lower level. Incidentally, it may be observed that the unusually fine catches of January 4-13 account for the fact that the average lift for pound nets in this month was greater in 1943 than in any one of the four preceding years (Table 3).

It is difficult from the information at hand to state exactly the date on which the effects of the general mortality began to be felt. Figure 1 gives the impression that the downward trend in the catch per lift began immediately after February 15. February 18 also might be selected as the first day with an average lift of less than 200 pounds and also as the first date on which the mean lift was lower than that of any preceding day and higher than that of any subsequent day. On the other hand, the possibility must be recognized that the mortality may have affected the catch per lift somewhat before rather than after the middle of February. In the normal fishery the catches increased as the season progressed (Table 3). The failure of the figures of Table 4 to give any indication of this seasonal increase possibly may be due to the fact that the smelt were beginning to die during the first half of February. The safest general conclusion, therefore, would appear to be that the mortality set in at some date near the middle of February. This conclusion is in agreement with information supplied by commercial fishermen as to the time at which large numbers of dead smelt were first observed.

Loss of production resulting from the mortality.—In view of the extremely high take of 914,546 pounds of smelt in the Michigan waters of Green Bay in January 1943 (Table 2) and the catch of 521,822 pounds during the first 17 days of February (Table 4), every prospect existed for a record commercial production of the species in that year. The general mortality, however, reduced the catch in the latter part of the season so greatly (Table 2) that the 1943 yield actually was the smallest since 1939 (Table 1) at which time the fishery was only in the process of development. The resulting loss of production was the more damaging in that it occurred at a time when the strict war-time rationing of meat made the maximum output of fish vitally important.

It is of some interest to estimate the quantity of smelt that might have been produced commercially in 1943 in the Michigan waters of Green Bay had the mortality not taken place. In making this estimate the figure for January has been accepted without change (Table 2). The possible catch for the latter part of the season, however, must be calculated from certain assumptions based on known conditions in the normal fishery. The first step in estimating the possible yield for February was to compute the catch for pound nets, the principal gear, during the last 13 days of the month as the number of lifts (1,321) times 276 pounds, the average catch per net over the period, January 14-February 17 (Table 4). Any error in the resulting estimate of 364,596 pounds is in the direction of conservatism as the

mortality was assumed not to have affected fishing intensity in February (there is some indication, however, of declining intensity toward the end of the month) and no adjustment was made for the seasonal increase in the catch per lift that normally might be expected to take place during the month. The total pound-net catch for February, with the yield for the last 13 days estimated, was determined as 886,418 pounds, or 1.28 times the actual catch. If the same proportionate increase is assumed to be applicable to the catch of other gears (and to the small pound-net catch for which gear records were lacking) the estimated potential production for February in all gears combined becomes 981,208 pounds.

The computation for March required first an estimate of the probable fishing intensity. Here it was assumed that had no mortality taken place the ratio of the number of lifts in March to the number in February would have been the same in 1943 as in the preceding years of 1939-1942. Since in these earlier years the number of pound-net lifts in March was 1.23 times the number in February, the estimated potential number of lifts in March 1943 was $1.23 \times 3,295$ or 4,053 (the February total of 3,290 in Table 4 was increased by 5 to correct for the 998 pounds of smelt for which records of gear were lacking). It was assumed further that had no mortality occurred in 1943 the catch per pound-net lift in March would have been equal to the 1939-1942 average of 484 pounds (Table 3). The possible March production in this gear was then computed as $4,053 \times 484$ pounds of 1,961,652 pounds. A similar computation for small-mesh gill nets yielded a figure of 104,832 pounds. For the remaining gears the potential March 1943 production was merely set at 21,048 pounds, the mean of the March catch in 1940-1942 for such gears. The March estimate for all gears, therefore, was 2,087,532 pounds.

For April as for the miscellaneous gears in March the possible 1943 take was set arbitrarily at the 1940-1942 mean—in this instance, 85,058 pounds.

The estimate of the quantity of smelt that would have been produced in the Michigan waters of Green Bay during the first four months of 1943 had no mortality occurred may be summarized as follows:

Month	*Production*
January	915,000
February	981,000
March	2,088,000
April	85,000
Total	4,069,000

The above figures give strong support to the belief that but for the general mortality the Michigan waters of Green Bay would have yielded a record commercial production of more than 4 million pounds of smelt in January–April 1943. As the actual catch was only 1,723,000 pounds the loss of production can be estimated as 2,346,000

pounds. Since the Wisconsin fisheries were affected similarly the total loss in the entire commercial smelt fishery must have been 3 million pounds or more.

The loss of output to the "amateur" dip-net fishery at the time of the spawning run was even greater. Although this spring fishery was always without organization and only a small percentage of the take could be marketed, the catch in the State of Michigan waters alone amounted to an estimated 5½ million pounds in 1942. With the elaborate arrangements that were made for the efficient and orderly marketing of the 1943 production (see introduction) we were fully justified in expecting a yield of 10 million pounds in the spring from all waters of Lakes Huron and Michigan. The actual catch was of course insignificant. The total loss for 1943 can be estimated, therefore, at about 13 million pounds.

Furthermore, since the 1944 catch was almost nil and that for 1945 was unimportant, the deficit in production for the 3 years combined (1943-1945) must be set at more than 40 million pounds. Despite known substantial recovery in 1946 the available data indicate that the yield was still far below the earlier "normal." It is probably valid to add to the deficit another 10 million pounds for 1946, making the total loss of food through 1946 resulting from the mortality in the neighborhood of 50 million pounds.

Prospects for the Recovery of the Stocks of Smelt

An immediate recovery of the stocks of smelt from the mortality was, of course, not to be expected. Since smelt first enter the commercial fishery in significant numbers as members of age-group II (Table 5) the entire take at the spawning period[3] in 1943 and virtually all of it during both the winter and spring of 1944 depended on survivors of the 1942-1943 epidemic. In both years the spawning-run catch was insignificant, and the 1944 commercial production was negligible (Table 1).

The first opportunity for an appreciable increase in the stocks came in 1945 when members of the "post-mortality" spawning of 1943 entered the fishery. To be sure, the spawning stock was extremely low in 1943; on the other hand, the chances for the survival of the young probably were good. The expectation of some improvement in the stocks of smelt in 1945 was fulfilled when the commercial fishermen produced a small quantity in the State of Michigan waters of Green Bay (Table 1) and conservation officers reported significantly greater numbers of fish in the spawning runs. The runs were still extremely light, however, and the records of the catch per lift of pound nets in Green Bay (Table 3) suggest that the general level of abundance of the population was less than 10 per cent of that of "pre-mortality" years.

[3]The statement that smelt enter the fishery at the age of 2 years holds for the spawning run as well as for the winter commercial fishery since maturity is not attained until that age is reached. Practically all II-group smelt are mature.

Further improvement in the stocks of smelt was anticipated for 1946 in which year recruitment was to be expected from an additional "post-mortality" spawning (that of 1944). An exact appraisal of 1946 conditions is not yet possible. Although statistics of the winter commercial fishery are not yet available, a marked increase in the take is suggested by the following 1944-1946 records of the quantities of smelt received on the Chicago wholesale market from Michigan and Wisconsin localities during the three months, January-March: 1944—none; 1945—747 pounds; 1946—49,958 pounds.[4] The April receipts, the bulk of which may be assumed to have come from the spawning-run fishery, were: 1944—15,229 pounds; 1945—16,262 pounds; 1946—110,005 pounds. Various reports on the 1946 spawning runs support the preceding evidence for a marked increase in the abundance of smelt.

It is with no inconsiderable trepidation, stemming from the memory of previous betrayal by the smelt, that I now undertake certain comments relative to prospects for the production of smelt in 1947 and later years. Given a good survival of the 1945 hatch an enormous rise can occur in 1947. The recoveries of 1945 and 1946 were made possible by the progeny of the small number of survivors of the 1942-1943 epidemic. In 1947, however, a second "post-mortality" generation will enter the fishery. If the survivors of the mortality could produce sufficient young in the 1943 and 1944 spawnings to account for the 1945 and 1946 increases, the larger spawning stock of 1945 should accomplish much more for the 1947 fishery. The spawning stock of 1946, the young of which will enter the fishery in 1948, was, according to all evidence, greatly increased over that of 1945. It seems reasonable to hold, then, that by 1948 or 1949 the abundance of smelt should cease to be limited by the number of spawners in preceding years.

Whether this theoretical course of recovery will be realized, only the passage of time will reveal. Unexpected good survival can hasten the process or poor survival can retard it. Nor can we overlook the possibility of a recurrence of the mortality! In this connection it would be comforting to feel that the present stocks of smelt consist principally of a strain that is immune to the ailment that destroyed most of the 1942-1943 populations and hence that through the process of selection the chances of another epidemic may have been reduced.

Improvement in the Growth Rate of Smelt Subsequent to the Mortality

The previous reference to Table 5 was concerned only with the demonstration that smelt enter the fishery at the age of two years. Attention is now called to a second feature of the data, namely, the

[4]The improvement in 1946 was doubtless not as great as the relative values of the figures for 1945 and 1946 would indicate. Unquestionably a certain "base quantity" of the catch is absorbed by local consumers before shipments to Chicago are begun. The Chicago receipts are interpreted best as repesenting part of the excess over local requirements.

TABLE 5.—*Numerical and percentage representation, average total lengths (inches), and average weights (ounces) of age groups of smelt in three samples from the Escanaba region of Green Bay*

Date of capture	Item	Age group (males)				Age group (females)				
		I	II	III	I-III	I	II	III	IV	I-IV
March 4, 1941	Number of fish	.....	35	11	46	1	36	12	1	50
	Percentage in age group	.....	76.1	23.9	.....	2.0	72.0	24.0	2.0	.....
	Average length	.....	6.7	7.4	6.9	5.3	6.9	7.9	7.6	7.1
	Average weight	.....	1.0	1.4	1.1	0.5	1.1	1.8	1.4	1.3
March 20, 1944	Number of fish	2	25	1	28	1	19	2	.....	22
	Percentage in age group	7.1	89.3	3.6	.....	4.5	86.4	9.1	.....	.....
	Average length	6.4	7.3	8.5	7.3	6.3	7.7	9.6	.....	7.8
	Average weight	1.0	1.5	2.6	1.5	0.9	1.9	3.4	.....	2.0
January 29, 1945	Number of fish	1	25	5	31	2	18	13	2	35
	Percentage in age group	3.0	80.6	16.1	.....	5.7	51.4	37.1	5.7	.....
	Average length	4.9	7.6	7.9	7.6	5.5	8.4	8.7	10.5	8.5
	Average weight	0.5	2.0	2.2	2.0	0.6	2.7	3.0	4.9	2.8

generally greater average lengths and weights of the smelt in Green Bay in 1944 and 1945 (after the mortality) as compared with fish of corresponding age in 1941 (before the mortality). The interesting possibility is suggested that the drastic reduction in the density of the population of smelt was followed by an improvement in the rate of growth. In the best represented age group (II), for example, the males averaged 0.6 inch longer in 1944 and 0.9 inch longer in 1945 than in 1941. The corresponding advantages in weight were 0.5 and 1.0 ounce; the average weight in 1945 (2.0 ounces) was double that in 1941 (1.0 ounce). The differences were even greater for the II-group females. These fish averaged 0.8 inch longer in 1944 and 1.5 inches longer in 1945 than in 1941. The weight advantages were 0.8 ounce and 1.6 ounces; females of age-group II were nearly 2½ times as heavy in 1945 as in 1941.

The greater size of II-group smelt in 1945 as compared with 1944 lends additional support to the assumption that growth improved subsequent to the mortality, as fish of this age captured in 1944 had spent only one growing season (that of 1943) in the "post-mortality" era whereas those taken in 1945 had had the advantage of two seasons (1943 and 1944) under the supposedly better conditions.

Data are too scanty to permit similar comparisons for age-groups I and IV (the latter represented only by females) or for the III-group males, although the available information for the last group does suggest increased growth. The sample of the III-group females also was small in 1944. The 1941 and 1945 samples of the III-group females indicate, however, that fish of that age were larger (0.8 inch longer; 1.2 ounces heavier) two years after the mortality than they were three years before it.

In order to gain a better idea of the dependability of the data that indicate improved growth rate subsequent to the mortality, statistical tests of significance (*t*- test) were applied by Dr. Ralph Hile to the several differences listed above. Without exception where the number of fish justified comparison the average lengths and weights of the age groups were significantly greater ($p < 0.01$ except for the weights of III-group females where $p < 0.05$) in 1944 and 1945 than in 1941. Furthermore, a real improvement in the size of fish in 1945 as compared with 1944 is indicated by the fact that the II-group males and females were significantly heavier ($p < 0.01$) in the former year. Females of this age group were also significantly longer in 1945 than in 1944 ($p < 0.01$); no real difference could be demonstrated, however, between the average lengths of the II-group males in these years.

The strong evidence for the improved growth of smelt after the mortality invites the conclusion that the reduction in the population was the cause of the change. The controlling mechanism might be a lessening of competition for food, or, conceivably, the lowering of the density of the population *per se* might have led to improved growth. Numerous examples of an inverse relationship between growth rate

and population density have been given in the literature. On the other hand, substantial fluctuations in growth rate have been observed that were not dependent on population density but were related to other factors such as meteorological conditions[5]. Reduction in the numbers of fish is offered as the most probable explanation of the observed improvement of the growth rate of the smelt in northern Green Bay. Scale collections in later years doubtless will throw considerable light on this problem.

A summary of this paper appears in the abstract.

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[5]The question of factors of growth can not be discussed in detail here; a recent review of the subject is to be found in my 1944 paper.

VARIATIONS IN NITROGEN CONTENT AND FISH PRODUCTION IN SMALLMOUTH BLACK BASS PONDS

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ABSTRACT

Ammonia, nitrite, nitrate, and organic nitrogen were determined at 10-day intervals for 24 ponds at Leetown, West Virginia. These ponds were stocked with 15,000 smallmouth black bass fry per acre and all fish reared in them were counted individually and weighed when the ponds were drained after an average season (during 1943) of 105 days. The purpose of the study was to determine what correlations, if any, existed between fish production and the nitrogen content of the water.

Correlations between ammonia, nitrite, and nitrate nitrogen and fish production were not evident. Larger quantities of these forms of nitrogen were present during the first half of the pond season than during the latter half.

A positive correlation was found between the organic-nitrogen content of the water and fish production. This form of nitrogen, probably as a result of plant decay, was present in larger quantities during the latter half of the season than during the early season. Ponds which averaged 0.56 and 0.65 pounds of bass per acre per day had average organic-nitrogen contents of 0.494 and 0.434 p.p.m. Ponds averaging 1.69 and 1.79 pounds of bass per acre per day averaged 0.811 and 0.746 p.p.m. of organic nitrogen, respectively.

INTRODUCTION

The quantities of ammonia, nitrite, nitrate, and organic nitrogen were determined in 20 experimental smallmouth black bass ponds at 10-day intervals throughout the 1943 season at Leetown, West Virginia[1]. The production of smallmouth black bass *(Micropterus dolomieu)* in these ponds was carefully recorded, since comparisons were being made among the different kinds of fertilizers used. Data on nitrogen determinations and fish production from six ponds of the 1940 season also were available for comparison.

There have been few intensive studies with the purpose of correlating fish production with the nitrogen content of the water. Schäperclaus (1938), in his textbook on pond-fish culture, concluded from the European data that it was still not possible to form a clear conception as to the value of fertilization with mineral nitrogen. He pointed out the need for further research on the nitrogen problem in fish ponds and urged fishery workers to conduct experiments in ponds as much alike as possible and stocked similarly.

During the 1942 season at Welaka, Florida, Meehean and Marzulli (1945) investigated the effects of different fertilizers on the produc-

[1]The chemical data for two ponds could not be compared with fish production because an adult largemouth black bass probably introduced by a heron or an osprey evidently had consumed the fry in one pond (H-20), and a catastrophe obviously occurred to the smallmouth bass fry shortly after their introduction into a second pond (H-3).

tion of largemouth black bass and correlated the results of determinations of the carbon: nitrogen ratios of the bottom muds of ponds and the nitrogen content of their waters with the production of fish. In comparing fish production in the different ponds, the pounds of fish produced per acre per day was used as the unit of comparison (Meehean, 1943). This unit of comparison was derived by dividing the pounds of bass produced per acre by the number of days the pond was operated. They found that the 8 highest-producing ponds (average 0.73 pounds per acre per day) had the lowest total nitrogen content (0.433 p. p. m.), while the 8 lowest-producing ponds had the highest average total nitrogen (0.462 p.p.m.). This range in total nitrogen content of the pond water is hardly significant, however. Organic nitrogen in the Welaka ponds varied between 0.296 and 0.459 p.p.m.; nitrite nitrogen from 0.0005 to 0.0124 p.p.m.; nitrate nitrogen from 0.054 to 0.114 p.p.m.; and ammonia nitrogen from 0.006 to 0.022 p.p.m. Meehean and Marzulli associated increased fish production with a small content of nitrogen in the water and a small loss in humus in the bottom mud.

Some ponds at Leetown in which large quantities of nitrogen have been used in the fertilizers applied have given good results in the production of smallmouth black bass. The evidence points toward the nitrogen content of the fertilizer as an important factor, and the object of this study accordingly has been to compare the nitrogen contents of fertilized and unfertilized ponds, as well as of those of high and low fish productivity.

Wiebe (1930) made nitrogen determinations for several ponds at the biological station of the Bureau of Fisheries at Fairport, Iowa. He was interested in the different forms of nitrogen as possible limiting factors in plankton production. A limiting factor was defined as "the element that becomes exhausted and thus causes a cessation of plant growth." Wiebe emphasized the point that aquatic animals upon which bass feed, are ultimately dependent upon plants for food and that increased plant growth should, in the end, mean increased fish production. In the "C" series of concrete ponds which he studied, the pond fertilized with soybean meal produced the largest crop of crustacea (1,812 per liter). This pond also had the highest average organic-nitrogen content (4.43 p.p.m.). The ammonia nitrogen in the pond varied between 0.052 and 0.600 (average 0.127) p.p.m. and the nitrate nitrogen between 0.032 and 0.150 (average 0.059) p.p.m. It can be seen that the average organic-nitrogen content of this pond was about 10 times the average total nitrogen recorded for the eight highest-producing ponds at Welaka, Florida, in 1942. In the three regular fish ponds ("D" series) at Fairport sampled by Wiebe, the organic nitrogen varied from 0.16 to 3.92 p.p.m., ammonia nitrogen from 0.016 to 0.224 p.p.m. and nitrate nitrogen from 0.010 to 0.120 p.p.m. Nitrite nitrogen was entirely absent in one pound throughout the season and occurred only once in each of the two remaining ponds

studied. Organic nitrogen in the unfertilized pond varied from 0.360 to 0.920 p.p.m.

Birge and Juday (1927) investigated the organic-nitrogen content of 84 Wisconsin lakes. The smallest amount found was 0.188 p.p.m. and the largest, 1.540. The mean was 0.493 p.p.m.

Domogalla and Fred (1926) determined the different forms of nitrogen, rate of nitrification, and rate of nitrate reduction in the chain of lakes about Madison, Wisconsin. The organic nitrogen varied from 0.640 p.p.m. in Lake Wingra to a maximum of 1.130 p.p.m. in Lake Waubesa. This latter lake usually had more than 1.0 p.p.m. of organic nitrogen. Ammonia nitrogen varied from 0.049 to 0.544 p.p.m. and nitrate nitrogen from 0.010 to 0.175 p.p.m.

Domogalla, Juday, and Peterson (1925) found that ammonia, nitrites, and nitrates comprised from 25 to 50 per cent of the total soluble nitrogen in Lake Mendota. These forms originated from the decay of organic materials contained in the mud and debris at the bottom of the lake. In the lake, ammonia, nitrites, and nitrates reached their highest concentrations between January and March; their lowest concentrations occurred in late summer and early fall. Rice (1917) had noted earlier in Winona Lake that nitrogen increased during winter and early spring due to the surplus of affluents and decay over effluent and fixation by plants.

The literature contains many references to the utilization of the different forms of nitrogen by phytoplankton and the larger aquatic plants. Plants readily use nitrogen in the form of nitrates, and Waksman, Hotchkiss, and Carey (1933) pointed out that nitrites can be used as a source of nitrogen by growing algae and diatoms just as well as the nitrate itself. Ammonia nitrogen is probably more readily used by the algae than is generally supposed. The large variations in the concentrations of ammonia, nitrite, and nitrate nitrogen in fish ponds at Leetown are, no doubt, due to the rapid growths of the filamentous algae *Spirogyra, Cladophora, Oedogonium,* and *Hydrodictyon* in the characteristically clear, hard water. These large variations occur within a matter of days or even hours.

It is suggested that one reason for the failure of investigations to indicate stronger correlations between the nitrogen content of the water and bass production is that nitrogen determinations have not been made in truly high-producing ponds. High production of bass is defined, for the moment, as production in excess of 150 pounds of bass per acre per season or 1.5 pounds of bass per acre per day. The maximum production of smallmouth black bass recorded at Leetown is 262 pounds per acre for a pond operated 120 days (2.19 pounds per acre per day). During th e1943 season, two pounds exceeded 2.0 pounds of bass per acre per day and 200 pounds of bass per acre for the season. Both of these ponds were "high" in organic nitrogen (0.775 and 0.945 p.p.m.).

Methods

The different forms of nitrogen were determined according to the procedures outlined in "Standard Methods for the Examination of Water and Sewage," American Public Health Association (1939). As is customary, samples for the determinations of organic nitrogen were not centrifuged. Organic nitrogen, therefore, includes nitrogen incorporated in the bodies of plankton organisms as well as soluble organic nitrogen in the form of amino acids, proteins, and peptides. However, these soluble compounds comprise by far the largest part of the organic nitrogen of fresh waters.

In the routine procedure followed, samples of water were secured from each pond at three points about equally spaced (on one side of the pond only) by thrusting 1-liter ground-glass-stoppered bottles well below the surface. The full sample was, therefore, a composite of three equal portions of the pond water. Samples were collected at 10-day intervals between April 18 and August 8. The number of rounds made of the ponds through the season was 10. In comparing early-season with late-season averages, the figures for the first five collection periods extending from April 18 to June 8 were compared with those for the last five rounds extending from June 17 to August 7, 1943, inclusive.

Samples were collected just before fertilizers were applied to the ponds so that usually about eight days elapsed between the time the fertilizer was applied and the analyses of the water were made.

The composition, pounds per acre per application, and number of applications of the various fertilizers used in ponds in which nitrogen determinations were made during 1943 and 1940 are given in Table 1.

The pond experiments were conducted in long, narrow ponds (about 50 feet wide) varying from 0.35 to 0.68 of an acre in area. They were supplied with hard water and stocked with smallmouth black bass fry at the rate of 15,000 per acre. The average length of time the ponds were operated was 105 days during the 1943 season. All bass removed at the end of the season were counted individually and weighed in groups after draining in a net for 45 seconds.

Ammonia Nitrogen

The lowest season averages for ammonia nitrogen occurred in those ponds which did not receive ammonia sulphate. There was little difference between the average ammonia-nitrogen content of the unfertilized ponds and that of ponds fertilized with cottonseed meal alone or in combination with superphosphate. In the unfertilized ponds, the ammonia nitrogen varied from a minimum of 0.000 to a maximum of 0.140. The season average (0.049 p.p.m.) for one control pond (H-2) was more than three times that of the other (H-16). The difference was attributed to the early-season abundance of *Potamogeton crispus* in Pond H-2 and its mid-summer decay. In Pond H-2, the ammonia

TABLE 1.—*Composition of fertilizers used in the experiments at Leetown*

Item	Formulas, pounds per acre per application and spacing, and total number of applications							
Combination formulae[1]	13-5-5	12-5-10	15-3-6	8-9-2	Cottonseed meal 1: superphosphate 1	Hay 10: superphosphate 1	Sheep manure 1: superphosphate 1	Cottonseed meal 1: superphosphate 1
Year	1943	1943	1943	1940	1943	1943	1940	1940
Ammonium sulphate (20.57 per cent N)	60	60	60	40	....	....	....	....
Superphosphate (20 per cent P_2O_5)	24	24	12	....	....	24	....	....
Superphosphate (16 per cent P_2O_5)	....	....	....	60	30[1]	....	15	15
Muriate of potash (50 per cent K_2O)	10	20	10	5	....	....	....	....
Cottonseed meal (6.56 per cent N, 2.5 per cent P_2O_5, 2.0 per cent K_2O)	....	....	....	....	30	....	....	15
Timothy hay (0.8 per cent N, 0.3 per cent P_2O_5, 0.6 per cent K_2O)	....	....	....	....	....	240	....	....
Sheep manure (1.65 per cent N, 1.00 per cent P_2O_5, 2.00 per cent K_2O)	....	....	....	....	....	....	15	....
Total pounds per acre per application	94	104	82	105	60	264	30	30
Interval between applications (days)	10	10	10	7	10	10	7	7
Total number of applications during the season	7	7	7	13-14	7	7	15	11-13

[1]The inorganic formulae in this table are based on the number of units of nitrogen (*N*), phosphoric acid (P_2O_5), and potash (K_2O) in a ton of the mixture without fillers. In the 13-5-5 combination, for example, 12.34 pounds of N, 4.8 pounds of P_2O_5, and 5.0 pounds of K_2O are added to the pond at each application. If 6 pounds of filler were added to make a total of 100 pounds for each application, the formula would be 12-5-5 instead of 13-5-5.

nitrogen rose from 0.056 p.p.m. on June 17, to a maximum of 0.140 p.p.m. on July 9, following the decay of the plants.

Control pond H-16 was typical in every respect of the unfertilized ponds at Leetown. The bottom was covered with a dense growth of *Chara* throughout the summer and the water remained very clear. At the beginning of the season 0.032 p.p.m. of ammonia nitrogen was present, but as the season progressed, the amount present diminished until the water was ammonia-free during the last two rounds of the ponds.

The highest average concentration of ammonia nitrogen (0.135 p.p.m.) occurred in the 15-3-6 ponds. This fact may be significant, since this series of ponds received only half the superphosphate used in the 13-5-5 and 12-5-10 ponds. Table 1 shows that all ponds fertilized with inorganic fertilizers during the 1943 season received the same amount of ammonium sulphate per acre. The reduction in the amount of superphosphate resulted in limited growths of filamentous algae in these ponds. If the filamentous algae use ammonia nitrogen directly or indirectly, the higher average ammonia-nitrogen content of these ponds might be correlated with the failure of abundant growths of filamentous algae to develop. The highest ammonia-nitrogen contents (1.400 p.p.m.) at any time occurred on May 25 in two ponds of the 15-3-6 series. Neither of these maxima could be associated with plant decay.

The season averages for ammonia nitrogen in the various series of ponds are compared in Table 2 with the smallmouth black bass. No correlation were found between this form of nitrogen and fish production.

The ammonia-nitrogen content of fertilized ponds averaged much higher during the first half of the season than during the latter half as is illustrated by Table 3. Vegetation grows rapidly at first, increasing enormously in bulk at the expense of the fertilizing elements. Thereafter, these elements are used as fast as they are added without a great deal of benefit to the fish, unless plant decay again releases them as well as valuable organic materials which can be used more directly by bacteria or fish-food organisms such as the Entomostraca and Chironomidae.

Nitrite Nitrogen

Nitrite nitrogen was usually present in small amounts in ponds fertilized with high-nitrogen purveyors. It was most frequently absent entirely in the two series of ponds receiving, respectively, timothy hay 10: superphosphate 1, and cottonseed meal 1: superphosphate 1.

The seasonal average values for the different ponds are compared with fish production in the same ponds in Table 2. No relationship was found between fish production and the concentration of nitrite nitrogen.

Amounts present in the different ponds varied from no detectable

TABLE 2.—*Seasonal averages for nitrogen in ponds receiving various fertilizers*

Number of ponds	Kind of fertilizer	Average pounds of bass per acre per day	Season averages (p.p.m.)			
			Ammonia nitrogen	Nitrite nitrogen	Nitrate nitrogen	Organic nitrogen
2	Cottonseed meal	0.56	0.037	0.029	0.203	0.494
2	None	0.65	0.032	0.006	0.140	0.434
3	15-3-6	0.67	0.135	0.009	0.150	0.503
2	Sheep manure 1: superphosphate (16 per cent) 1	0.68	0.041	0.008	0.164	0.499
2	Cottonseed meal 1: superphosphate (16 per cent) 1	0.91	0.012	0.005	0.080	0.547
2	8-9-2	0.95	0.048	0.021	0.098	0.630
2	12-5-10	1.06	0.119	0.011	0.160	0.547
3	13-5-5 dry	1.08	0.122	0.007	0.100	0.628
3	Hay 10: superphosphate (20 per cent) 1	1.69	0.104	0.008	0.040	0.811
3	13-5-5 wet	1.79	0.085	0.003	0.050	0.746

TABLE 3.—*Early- and late-season average concentrations (p.p.m.) for the different forms of nitrogen occurring in ponds at Leetown during 1943*

Number of ponds	Kind of fertilizer	Ammonia nitrogen			Nitrite nitrogen			Nitrate nitrogen			Organic Nitrogen		
		Season average	Early-season average	Late-season average	Season average	Early-season average	Late-season average	Season average	Early-season average	Late-season average	Season average	Early-season average	Late-season average
2	None	0.032	0.030	0.035	0.006	0.007	0.005	0.140	0.270	0.050	0.434	0.356	0.511
3	12-5-10	0.086	0.210	0.028	0.014	0.025	0.003	0.130	0.400	0.030	0.617	0.529	0.703
3	13-5-5 dry	0.122	0.221	0.023	0.007	0.011	0.002	0.100	0.330	0.020	0.628	0.601	0.655
3	13-5-5 wet	0.085	0.103	0.067	0.003	0.004	0.001	0.050	0.160	0.010	0.746	0.573	0.919
3	15-3-6	0.135	0.244	0.026	0.009	0.014	0.004	0.150	0.440	0.060	0.503	0.444	0.561
3	Timothy hay 10; superphosphate 1	0.104	0.181	0.027	0.008	0.014	0.001	0.040	0.110	0.030	0.811	0.745	0.878
3	Cottonseen meal 1; superphosphate 1	0.024	0.018	0.030	0.004	0.003	0.004	0.060	0.100	0.090	0.602	0.543	0.661

quantity to 0.065 p.p.m. during the 1943 season. As much as 0.115 p.p.m. was recorded in a pond fertilized with cottonseed meal during 1940. All maxima occurred during the early half of the season. Table 3 illustrates the fact that nitrite nitrogen is usually present in larger quantities during the first half of the season than during the latter half.

Nitrate Nitrogen

In most of the ponds nitrate nitrogen was most plentiful at the very beginning of the season. The maximum value recorded (1.25 p.p.m.) occurred on the first sampling date in pond H-7 which was fertilized with a 12-5-10 inorganic combination. There were times in every pond, with the exception of one pond fertilized with sheep mature and superphosphate during 1940, when nitrates were completely exhausted. This absence of nitrate occurred frequently during the latter half of the season.

Table 3 shows that nitrate nitrogen was decidedly higher during the first half of the season.

Nitrate-nitrogen content and fish production in the different series of ponds are compared in Table 2. If there is any relationship, the abundance of nitrates is correlated negatively with bass production. since the lowest season average of nitrate nitrogen occurred in the highest-producing series of ponds.

The average concentration of nitrate nitrogen in some of these series of ponds exceed that of ponds investigated by Wiebe (1930) and Meehean and Marzulli (unpublished report). High early-season values in the Leetown ponds tend to make the full-season averages high.

Organic Nitrogen

Of the forms of nitrogen determined in this study, the organic nitrogen was the least variable nitrogen constituent of the pond water and probably the only form correlated with fish production.

A survey of the data (Table 4) indicates a positive correlation between the organic-nitrogen content of the pond water and the production of fish. In other words, the highest-producing ponds with respect to pounds of bass per acre per day contained the highest average concentration of organic nitrogen. This result is in direct opposition to the findings of Meehean and Marzulli (NB) who believed that high production was associated with minimal quantities of nitrogen in the water.

The highest average concentration of organic nitrogen in the Leetown series of ponds during 1943 was 0.811 parts per million. It occurred in the hay-superphosphate ponds which produced the highest average number of pounds of smallmouth black bass per acre (189.97).

In contrast to the other forms of nitrogen, the organic nitrogen was generally somewhat higher during the latter half of the season than during the first half. This fact may be attributed to the prevalence

TABLE 4.—*Relationship between organic nitrogen and the production of smallmouth black bass in ponds at Leetown, West Virginia*

Number of ponds	Kind of fertilizer	Organic-nitrogen (p.p.m.) averages for each sampling date										Organic nitrogen (season average)	Pounds of bass per acre	Pounds of bass per acre per day
		April 18-23, 1943	April 29-30, 1943	May 10-11, 1943	May 24-25, 1943	June 7-8, 1943	June 17-18, 1943	June 28-29, 1943	July 9-10, 1943	July 19-20, 1943	Aug. 6-7, 1943			
2	None (controls)	0.280	0.340	0.260	0.480	0.420	0.540	0.590	0.462	0.470	0.495	0.434	64.87	0.65
3	15-3-6	0.347	0.507	0.547	0.400	0.420	0.580	0.513	0.583	0.497	0.633	0.503	71.49	0.67
2	Cottonseed meal 1: superphosphate (16 per cent) 1	0.320	0.840	0.540	0.460	0.530	0.580	0.720	0.610	0.420	0.450	0.547	109.49	0.91
2	12-5-10	0.180	0.560	0.500	0.560	0.600	0.780	0.470	0.660	0.500	0.650	0.547	109.02	1.06
3	13-5-5, dry	0.427	0.853	0.507	0.587	0.633	0.680	0.600	0.623	0.613	0.757	0.628	117.63	1.08
3	Timothy hay 10: superphosphate (20 per cent) 1	0.427	1.120	0.773	0.616	0.787	0.573	0.640	0.811	0.960	1.407	0.811	189.97	1.69
3	13-5-5, wet	0.267	0.427	0.467	0.840	0.867	0.727	0.720	0.875	0.873	1.400	0.746	184.35	1.79
....	.....	.....	April 29, 1940	May 13, 1940	May 27, 1940	June 10, 1940	June 24, 1940	July 8, 1940	July 22, 1940	Aug. 5, 1940	Aug. 19, 1940	.....	.....	.....
2	Cottonseed meal	.....	0.760	0.528	0.320	0.460	0.230	0.224	0.460	.....	.....	0.494	23.51[1]	0.56
2	Sheep manure 1: superphosphate (16 per cent) 1	.....	0.740	0.710	0.132	0.320	0.424	0.280	0.860	0.500	0.520	0.499	64.89	0.68
2	8-9-2	.....	0.560	0.620	0.096	0.560	0.600	0.264	1.200	0.960	0.500	0.630	83.22	0.95

[1]The ponds fertilized with cottonseed meal were operated only 55 and 57 days in 1940, whereas all other ponds were operated about 100 days (average 105).

of plant decay which has been characteristic of ponds high in fish production. Aquatic plants contain only about 2.0 per cent nitrogen, but their quantity in fish ponds is frequently enormous. They are, unquestionably, a great storehouse for nitrogen as well as for carbohydrates and other foodstuffs, which, if made available at proper intervals, could support large numbers of bacteria, crustaceans and bottom animals throughout the summer period.

Summary

1. Larger quantities of ammonia, nitrite, and nitrate nitrogen were present in 1943 in the ponds at Leetown during the first half of the pond season (average 105 days) than during the latter half.

2. Nitrate nitrogen was abundant very early in the season, but disappeared rapidly, probably as a result of the rapid growth of plants. This form of nitrogen was completely exhausted at some time in all ponds of the 1943 series, usually on several occasions, and principally during the latter half of the season. If there is any correlation between nitrate nitrogen and fish production, it is negative in this series of ponds.

3. A positive correlation between the organic-nitrogen content of the water and fish production is strongly indicated. Organic nitrogen, probably as a result of plant decay, is present in larger quantities during the latter half of the season than during the early season.

4. The larger aquatic plants and perhaps filamentous algae, too, could be destroyed at intervals during the operation of the pond to assure more frequent turnover of nitrogenous materials and carbohydrates as food for plants and animals. Cost of fertilization would probably be reduced and the production of fish increased by management of the aquatic plants.

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A LABORATORY STUDY OF FISH POPULATIONS

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INTRODUCTION

Laboratory population studies have been made using a great variety of organisms other than vertebrates. They are so adequately reported and reviewed by Gause (1934), Chapman (1928), Park (1939, 1941), and Pearl (1927) that the reader is referred to these papers. The only such study on a vertebrate animal to come to the attention of this author is that of Breder and Coates. Such a scarcity of vertebrate studies is not surprising because of the necessary space and time required. The study of *Lebistes*[1] reported in the following paper required three years and it represents only a beginning of the solution of the many interesting possibilities suggested.

In fish management the problems of carrying capacity, cropping of the yield, cycles of abundance, effect of crowding on size, etc., can be approached more effectively through an understanding of principles revealed in experimental population studies.

Breder and Coates (1932) reported on a laboratory study of populations of *Lebistes* and demonstrated the theoretical logistic population curve for a fish. Among other conclusions was the statement that "artificial populations, irrespective of their original constitution, arrive at a steady state in which the sexes are in the ratio of one male to two females." This report on a "steady state" suggested the possibility of certain further experiments which could be carried out in order to determine the optimum cropping rate in such a population. This would involve the greatest possible yield of fish obtainable from a body of water and still retain an adequate breeding population. The author undertook this task, after consulting with Dr. Breder but found that his populations did not maintain this "steady state," and it appeared inadvisable to undertake the cropping experiment as planned until more was known about populations of this species.

The following report of the experiments is presented in order to add to our understanding of the dynamics of fish populations, to interpret the apparently uneven sex ratio, and to point out certain environmental requirements necessary for an experiment such as this one was intended to be.

MATERIALS

Thirteen balanced aquaria of 26-liter capacity were stocked with one male and two female *Lebistes* each on October 28, 1939. About 1 inch of washed torpedo sand was placed in the bottom and in this were

[1]Common guppy (*Lebistes reticulatus* (Peters)).

rooted numerous *Valisneria* plants. The aquaria were uniformly lighted for 15 hours each day with artificial light. The fish were fed all they would eat of live *Daphnia*, dried fish foods, and occasional *Tubifex*. In the earlier parts of the experiment, before the fish became so abundant, it was possible to keep live *Daphnia* before them at all times. As the populations increased, it was frequently impossible to raise enough *Daphnia* in the space available so that dried foods were used as a supplement. The laboratory room was heated with the University steam heat, and the only control was the regular room thermostat. The temperature was constantly recorded by keeping the cylinder of a soil thermograph in the water of tank No. 7. The average temperature was 26°C. with the greatest range from 19° to 34°C. In order to prevent excess accumulation of salts due to evaporation, 3 liters of the aquarium water were removed and replaced by dechlorinated water every 2 weeks. Chemical analyses of the water revealed no such harmful accumulations. Beckman readings on pH ranged from 8.0 to 8.65.

Similar experiments were attempted with *Gambusia* and *Xiphophorus* but these species proved to be unsuitable, probably because the available tanks were too small.

Method of Counting and Weighing

At intervals of every two months the fish of each tank were counted and weighed. They were moved by means of a small net to a battery jar. Then, by pouring off the water and allowing the fish to go out with it one at a time into smaller containers, they were separated into three jars containing males, females, and immature specimens respectively. After being counted they were combined for weighing. A 6-inch square cheesecloth was pushed down into a 3-inch dip net which was 3 inches deep. The net was then placed on a battery jar and the fish and water were poured into the cheesecloth. The cheesecloth with fish was removed and excess water allowed to drain off. The damp cheesecloth containing the fish was placed in a paper cup and covered with the bottom half of another paper cup inverted above the fish to prevent evaporation.

The cup with fish was placed on the pan of a triple beam balance, and the weight read to hundredths of a gram. The cloth was then removed, held over the proper aquarium, and the fish allowed to drop back into the water. The cheesecloth was then put back into the paper cup, covered, and weighed. This weight subtracted from the first weight gave the weight of the fish. The number of deaths resulting from handling was so small that it was insignificant.

Population Dynamics

Lebistes are predatory on their own young, especially when the excess live food available decreases. On one occasion a fish was observed to turn and eat its own young immediately after giving birth

and before the young could sink to the bottom. In the early part of this experiment the number of fish increased rapidly because of the small number of individuals which were large enough to eat the young. A graph of the population changes in one of the aquaria (tank 8) is shown in Figure 1. The total weight is seen to increase more slowly than the number of fish. As the weight increased to the point where the first-born fish became predatory on the young, the number of fish gradually declined. As this first age group attained a size large enough not to be eaten but to start preying on the younger fish, there soon ceased to be any survival of newborn young.

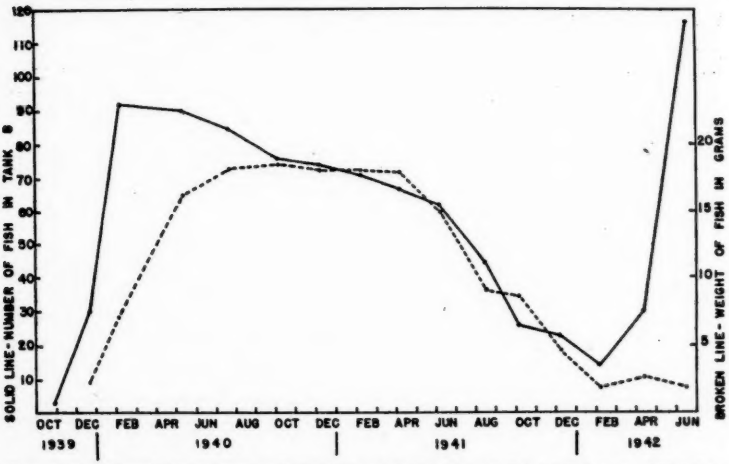
SOLID LINE - NUMBER OF FISH IN TANK 8
BROKEN LINE - WEIGHT OF FISH IN GRAMS
OCT DEC FEB APR JUN AUG OCT DEC FEB APR JUN AUG OCT DEC FEB APR JUN
1939
1940
1941
1942

FIGURE 1.—Population curves of numbers and weights of fish in Tank 8. (Weights in grams shown by broken line.)

The increase in weight of individual fish kept pace with the natural deaths, including predation, so that the weight curve remained relatively steady for about a year, through the latter part of 1940 and the earlier part of 1941. This relative stability of weight suggests the possibility that a tank of a given size is capable of supporting only a certain mass of fish. The weight of individual fish could thus increase only as the number decreases. This phenomenon is involved in the concept of "carrying capacity" in natural bodies of water where, for example, ponds of a certain size may support a large number of stunted fish or a smaller number of larger ones. Owing to the fact that the food source in these laboratory populations is not a natural one, the expression "carrying capacity" is not used here. Up to this point the results confirmed those reported by Breder and Coates. However, by carrying the experiment further, it was found that the curve

TABLE 1.—*Number of fish per tank*

	1939		1940					1941						1942		
Tank Number	Oct. 28	Dec. 20	Feb. 6	May 11	Jul. 20	Oct. 5	Dec. 7	Feb. 8	Apr. 6	Jun. 6	Aug. 15	Oct. 4	Dec. 6	Feb. 5	Apr. 11	Jun. 14
1	3	33	73	96	97	87	85	84	82	80	46	42	36	34	30	23
2	3	45	153	150	117	82	80	80	79	78	47	40	39	33	28	23
3	3	3	108	108	91	54	52	52	45	39	30	23	21	11	30	52
4	3	7	138	187	132	91	95	85	83	83	43	37	24	12	9	9
5	3	14	128	117	93	61	61	57	54	47	30	53	98	84	123	85
6	3	19	83	65	64	58	57	54	53	47	37	31	20	11	9	11
7	3	3	50	108	85	61	59	56	57	44	16	46	60	22	18	26
8	3	30	92	90	85	76	74	71	67	62	44	26	23	14	30	116
9	3	61	120	157	118	47	44	42	37	30	19	64	81	70	96	101
10	3	9	58	148	89	74	73	71	67	63	38	28	14	8	17	39
11	3	42	71	77	72	70	70	68	63	62	34	25	17	5	16	16
12	3	11	117	225	88	63	61	57	56	50	29	7	2	....[1]	....	....
13	3	4	48	66	66	59	60	58	56	46	28	26	33	35	50	41
Average	3	22	95	123	92	68	67	64	61	56	34	34	36	28	38	45

[1]All fish dead.

declined to a low point from which it again arose. Owing probably to old age the fish began to die more rapidly, so that there is seen a more rapid decline in both numbers and weight during the summer of 1941. A discussion of temperature later in the paper shows that this factor played a significant part. After the population dropped to a size similar to that in 1939, thus reducing predation, the newborn fish were again able to survive in numbers sufficient to start a second cycle of abundance in 1942. The author was engaged in out-of-town work with fishes during the summer of 1942 and was unable to continue the experiment.

The relation of weight to numbers for June, 1942, is seen to be very different from that in February, 1940, because of the differences in age and vigor of the adult fish. By June 1942, all of the heavy adult fish of the first population peak had died while in February, 1940, the three original stock fish were present and heavy.

The rate of increase of numbers in the 13 tanks was not identical as can be seen in Table 1. The maximal numbers were attained between February and May of 1940. The maximal weights came later as is shown in Table 2 with 9 of the 13 tanks reaching the maximum in April the following year. A graph of the averages of the 13 tanks for each date (Figure 2) shows this fact and in addition shows that the weight remains constant, or even increases, as the number of fish decreases.

The population increase in all 13 tanks from October, 1939, to May, 1940, shown in Figure 2, forms the "S" shaped logistic curve. This curve represents the trend in populations of all organisms studied and is well known in human populations. Next comes the period of decline already discussed as it occurred in Tank 8. After August, 1941, some of the populations had begun to increase again while others were still decreasing.

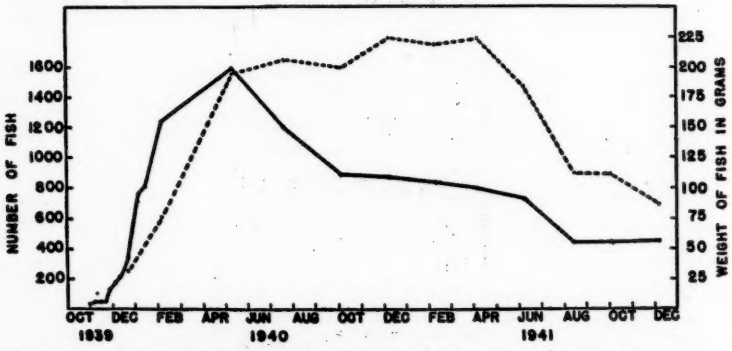

FIGURE 2.—Curve of numbers and weights of fish in all 13 tanks. (Weight in grams shown by broken line.)

Effects of Temperature

When deaths occurred the fish were removed, preserved in alcohol, and labeled as to tank number, date, and sex. The deaths for each week are shown in columns in Figure 3. The highest temperatures for the individual days in each week were averaged and recorded by the solid line above the deaths. It is seen that during or immediately following each of the periods of highest temperature there occurred the greatest number of deaths.

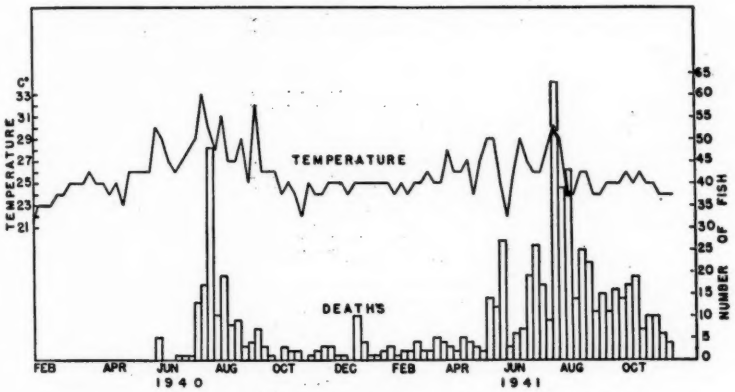

Figure 3.—Relationship of temperature to death rate in *Lebistes*.

Though temperatures reached higher levels in 1940 than they did in 1941[3], the number of deaths is seen to be much greater in the latter year. This is easily understood when it is remembered that the populations in 1940 contained young vigorous fish. By 1941 the fish were old and many were near the point of death before the advent of hot weather, as seen by the number of deaths each week during the year. Figures 1 and 2 show a slightly accelerated decline in the populations during the hottest months of 1940 and a marked decline in 1941. If this sharp decline in populations had not occurred, it is very likely that the end of the first cycle and the beginning of the next would not have been observed by the time that the experiment was concluded. This effect is somewhat unfortunate from one point of view, and to prevent it in further experiments a room with a brine cooling system has been provided. From another point of view it is not so unfortunate since this condition exists in natural populations. Fish managers have stated that the greatest fish mortality comes in the hottest months.

[3]Ice was placed around the tanks on the hottest days of 1941.

TABLE 2.—*Weights of total fish per tank*

	1939	1940					1941						1942		
Tank Number	Dec. 20	Feb. 6	May 11	Jul. 20	Oct. 5	Dec. 7	Feb. 8	Apr. 6	Jun. 6	Aug. 15	Oct. 4	Dec. 6	Feb. 5	Apr. 11	Jun. 14
1	2.5	5.8	15.4	9.4	18.4	19.8	19.3	20.1	17.9	12.5	16.5	15.2	15.0	14.2	10.2
2	2.9	8.9	18.7	19.2	18.4	21.4	22.0	23.2	21.3	13.2	16.8	17.3	15.5	14.4	12.1
3	2.4	4.8	15.0	15.0	13.1	20.5	16.0	14.9	12.0	8.4	7.6	5.8	3.3	4.1	2.5
4	3.0	4.6	13.7	13.9	13.7	16.0	15.2	16.2	15.5	9.6	9.0	6.1	3.4	3.2	0.5
5	2.0	5.7	12.9	14.6	12.9	15.4	15.0	13.2	10.3	4.1	3.5	3.6	2.9	3.1	1.9
6	1.7	5.5	14.4	16.4	15.5	17.0	15.8	15.3	12.9	9.9	11.0	6.9	4.9	5.1	2.7
7	1.6	3.4	10.1	13.8	8.4	10.8	10.8	12.2	8.8	3.4	3.9	3.1	0.6	1.0	1.2
8	2.3	7.2	16.2	18.3	18.6	18.2	18.2	18.0	15.1	9.2	8.6	4.8	1.8	2.6	1.8
9	3.1	7.4	16.6	16.4	7.6	8.4	8.9	8.0	7.1	3.8	4.4	4.9	3.5	3.3	3.3
10	2.1	4.9	15.9	17.1	18.7	19.5	20.5	20.7	19.4	12.0	11.6	6.6	4.8	3.0	2.9
11	3.5	8.2	16.9	19.2	19.2	20.5	21.5	22.4	20.7	11.2	11.1	7.2	2.9	1.9	2.3
12	2.2	5.5	14.8	14.7	15.9	16.4	16.8	17.9	15.4	7.8	2.2	0.7	....[1]	....	....
13	2.4	4.9	15.8	17.1	16.9	20.0	20.3	21.0	14.1	6.1	4.5	3.5	2.2	1.7	1.7
Average	2.4	5.9	12.8	15.8	15.2	17.2	16.9	17.1	14.7	8.6	8.5	6.6	5.1	4.8	3.6

[1]All fish dead

The manner in which high temperatures bring about the mortality was not investigated here, but it is likely that the lowered oxygen supply is at least a contributing factor.

Sex Ratios

As in many other species, male *Lebistes* appear to lack vigor and die at a lower age than females. This condition is revealed by Figure 3 which shows that at high temperatures many more males than females died. Figure 4 was prepared to show the shift in the relative numbers of males and females surviving during the year 1941. In June of 1941 one could have said that there existed a 1:1 sex ratio. If he had not seen these fish until August he would have said there apparently existed a ratio of 2 females to 1 male, or in October 3 females to 1 male, and in December nearly 4 females to 1 male. By February, 1942, so many of the second cycle young had reached sexual maturity that it was difficult to distinguish them from those of the first cycle. In some of the tanks, however, where they could be distinguished there were as many as 8 times as many old females as males.

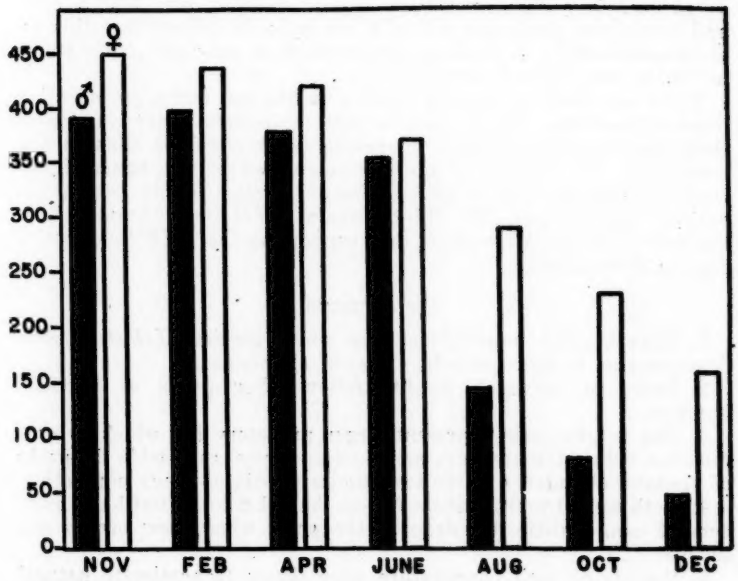

Figure 4.—Sex ratios of *Lebistes* from November 1940 to December 1941.

Discussion

Lebistes populations, under the conditions of these experiments, appear to have cycles of abundance rather than the hitherto reported type of population dynamics for cultures of a single species. In the latter type of population the "steady state" is reached. These cycles of abundance resemble results obtained where two species, a predator and a prey, are represented and where the peak of the predator population curve follows after the peak of that of the prey (Gause, 1934). One could well assume that both predator and prey are present since the younger fish are prey for the older predators. The curve of numbers fits well into the two species concept as the curve of the prey, while the weight curve fits that of the predator.

Fish populations in natural waters show the same fluctuations in size-weight relationships, and cannibalism is also undoubtedly an important factor.

Breder accepted the "XY" genetic constitution, which ordinarily produces a 1:1 sex ratio, though he had good evidence to show that under the conditions of his experiments and with his strain of *Lebistes* the sex ratio was 1 male to 2 females at birth. This conclusion implies that half the males died between the time of fertilization and birth. To quote him, "With an XY genetic constitution, and both a birth and death rate producing a 1 to 2 sex ratio, it follows that this environmental effect is similarly operative both pre- and post-natally, under the conditions described."

There are many conflicting reports on the sex ratios among other live-bearing fishes, and it may be that the genetic determination of their sex is unstable. Much interesting work could be done in this connection. The results on sex ratios reported in this paper should lead one to be cautious of determining such ratios simply from observations on collections. The Illinois strain of *Lebistes* appears to have the conventional 1:1 sex ratio, thus supporting the "XY" concept of genetic determination.

Conclusions

1. Experimental populations of a single species *(Lebistes)* were demonstrated to show periodic cycles of abundance.
2. Peaks of maximal weights follow after peaks of maximal numbers.
3. The weight peaks represent larger predatory fish which by cannibalism reduce the numbers, and thus these peaks resemble the peaks of predator abundance in the two species (predator-prey) population.
4. Both weight and numbers fall as the old fish die until the numbers of cannibalistic fish drop to the point where new broods can survive.
5. Periods of high temperature were shown to accelerate natural deaths in the populations.

6. An initial sex ratio of approximately 1:1 was shown to shift as the fish aged to the stage where 3 to 4 or more times as many females as males survived.

ACKNOWLEDGEMENTS

The author wishes to acknowledge his gratitude to Dr. David H. Thompson, Mr. James V. Lawrence, Dr. George W. Bennett, and Dr. C. M. Breder for suggestions and aid in carrying out the experiments, and to Dr. W. C. Allee, Dr. S. C. Kendeigh, Dr. D. F. Hansen and Mr. P. G. Barnickol for advice on the manuscript.

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A TAGGING EXPERIMENT ON THE FISH POPULATION OF THIRD SISTER LAKE, MICHIGAN[1].

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INTRODUCTION

The present report is from data gathered during the course of an experiment planned to determine the size of the fish population of Third Sister Lake, Michigan, by the use of tags, and was part of a general investigation concerning the bionomics of this lake conducted by the Institute for Fisheries Research, Michigan Department of Conservation. The study was under the general direction of Dr. A. S. Hazzard, Director, and Dr. C. J. D. Brown, formerly Aquatic Biologist, of the Institute.

The phase of the investigation reported here is concerned only with the data gathered in connection with the tagging of fish in the lake. Parts of this research have been published (Brown and Ball, 1943) and others will appear when they are completed.

A complete description of the lake has been published in reports of other phases of the investigation and only the mention of its general features will be made here. Third Sister Lake is oval in shape and has a surface area of 10 acres, a maximum depth of 55 feet, and stratifies chemically and thermally during the summer. The slope of the bottom in most parts of the lake is steep from shoreline to deep water, thus limiting the littoral zone to a relatively narrow band around the lake margin. The littoral zone extends to a depth of approximately nine feet and supports dense beds of submerged aquatic plants. Yellow water lilies border the shoreline of approximately two-thirds of the lake. The lake has no permanent inlet or outlet.

Third Sister Lake is permanently closed to fishing and its location in the center of a forestry tract owned by the University of Michigan and its proximity to the lodge of a caretaker made the loss of fish due to poaching quite unlikely.

Although the population estimate by the use of tags was not carried to a successful conclusion, other information was gained from the marking of the fish in the lake and it is this data that will be reported here. One phase of this program was terminated by what is believed to have been a complete kill and nearly complete recovery of all fish in the lake, and data were gathered on the survival of fish that had been tagged and released at varying intervals prior to the poisoning. From the tagging experiment also came information concerning the movements of fish within a limited habitat such as offered by Third Sister

[1]Contribution from the Michigan Institute for Fisheries Research.

Lake; a limited amount of information concerning the growth increase of tagged fish; and notes on the effect of tags upon the fish.

At the time of the poisoning of the lake 15 species of fish were recovered, of these 4 were game fish, 5 coarse fish, and 6 were forage fish. The important fish species as far as this study was concerned were the bluegills (*Lepomis machrochirus*), largemouth bass (*Huro salmoides*), bullheads (*Ameiurus natalis*) and pumpkinseed sunfish (*Lepomis gibbosus*).

General Procedure

Preliminary work of the investigation was started in the fall of 1938 and actual tagging operations began in May, 1939. As originally planned a portion of the fish population was to be tagged and an estimate of the entire population made from the ratio of marked to unmarked fish returned in nets set in the lake. When it was found that an accurate population estimate could not be made due to conflict with other phases of the investigation it was decided to continue marking the fish as well as netting operations until the time of the removal of the fish population by poison in order to obtain information on the number of tagged fish surviving over varying periods of time subsequent to tagging.

It was first planned to take all fish to be used in the population study and other phases of the investigation by fyke nets, but it became evident early in the first year's work that the number of fish that could be taken from this lake with the nets available, and suitable for use under the existing conditions, would not be adequate for a population study, and that nets would be entirely unsatisfactory for collecting fish needed in other phases of the work. Therefore hook and line fishing was employed to supplement the catch of the nets.

Equipment

During the summers of 1939 and 1940, and the spring of 1941 four fyke nets were used, three being kept in the lake at all times and the other out for repairs and drying. In 1939 and 1940 the nets were in the lake from the time the ice cover left until the time it formed again. Nets were set under the ice cover for short periods with no success. In 1941 nets were used from the time of the break-up of the ice until the poisoning on May 6. Nets of other types, both larger and smaller, were used for short periods of time during the course of the investigation but the fyke nets in operation proved the most satisfactory for use in the lake. The mesh of the traps in the nets was of such a size that allowed the escape of young-of-the-year bluegills and other fish of similar size. A few fish were taken with a seine but the yielding bottom, heavy marginal vegetation, and the necessity of working alone limited the use of the seine. The nets were lifted at least twice each day, morning and evening, all fish removed and the nets reset.

The nets were moved to new locations in the lake each week. Some areas of the lake were definitely more favorable habitats than others for the fish considered in this study and it was in these areas the nets were most often set. The steep contour of the lake bottom restricted, to some extent, the use of the fyke nets in certain sections of the lake.

Types of Tags Used in the Experiment

Three types of tags were used during the course of the investigation, the majority of them being adult fish tags made of monel metal. Thirty-three circular tags of a special design were also used. Ninety-six fingerling tags were used in marking the smaller fish (under 110 millimeters total length). These fingerling tags were of faulty material which often cracked in placement and showed a tendency to corrode rapidly and it seems probable that few of the fingerling tags remained on the fish for any appreciable length of time.

Methods of Tagging and Clipping

The majority of the tags were placed midway on the right side of the lower jaw by encircling the mandibular bone with the tag and then rounding it with a small pair of taper-nosed pliers. On a few of the largemouth bass and larger bluegills the tags were paced on the maxillary bone. These tags were not rounded. The total number of tags so placed was small and it was not possible to determine whether the maxillary tags would remain on the fish for a longer period than the mandibular tags but the condition of the few fish recovered indicated that in most cases the maxillary tags had caused less irritation to the fish than the mandibular tags. During the summer of 1939 the major emphasis was placed on tagging the fish captured and only a few fish, 10 bluegills, 14 bullheads, and 1 pumpkinseed sunfish were fin-clipped. No largemouth bass were fin-clipped in 1939. By the spring of 1940 it had become apparent that the original aim of estimating the population by tagging could not be satisfactorily completed and subsequent to that time the major effort was confined to fin-clipping the fish, with the exception of the largemouth bass which were tagged.

The clipping of the fins was done with heavy kitchen shears by cutting the fin at the joint. By removing different fins and combinations of fins, the fish released in certain areas could be recognized on recapture as coming from that region.

A few fin-clipped fish showed some regeneration of the fins but these were recognizable by the malformation of the fin. After a little experience no difficulty was encountered in the proper removal of the fins of the centrarchids but the removal of the fins of the bullheads so that they would not regenerate was more difficult. The regenerated fins of the bullheads were quite recognizable.

The mortality directly or indirectly attributable to the handling of the fish while tagging appeared to be very low. As the lake shoreline was covered by boat at least once and usually several times each day

in connection with other phases of the investigation it was possible to check the mortality of the fish quite closely. The few that apparently died as a result of handling floated to the surface of the lake within a day or two after being released during the hottest part of the summer.

Results of Tagging Experiments

Table 1 shows the number and per cent of each tagged fish species recovered at the time of poisoning. In Table 2 are shown the number of fish tagged and clipped during the two summers and the number and the per cent of each species returned alive by hook and line or by nets.

Of the 486 bluegills tagged in 1939, 96 were marked with defective fingerling tags. Five of the 96 were recaptured and 3 found dead. All live returns were made within 50 days and all dead fish recovered within 6 days following tagging. On three of the five live fish recaptured bearing fingerling tags it was noted that the tags were cracked but not parted. Seventeen (4.3 per cent) of the 390 bluegills tagged with adult tags were returned alive in 1939 and 4 (1 per cent) were found dead. In 1940 only 43 bluegills were tagged and of these 1 was returned. Twenty bluegills tagged in 1939 were recovered in 1940, 17 being captured alive and 3 were found dead. All tagged fish bore adult tags.

All marked fish recaptured were returned alive to the lake as soon as the data concerning the individual fish had been recorded.

It is believed that the low returns of tagged fish in the nets may have been due in part to the fish becoming "net shy" after once having been captured. The water in the lake was quite clear during most of the netting season and the nets were discernible in water as deep as nine feet which was about the lower limit the nets were set due to the presence of a thermocline and accompanying oxygen reduction at that depth.

Only seven of the 35 bluegills that had been recaptured in nets or by hook and line subsequent to tagging and then returned alive to the lake were recovered at the time of the poisoning.

Five of the seven largemouth bass captured subsequent to tagging and returned to the water were recovered at the time of the poisoning.

Of the 50 bullheads recaptured after tagging returned alive to the lake 24 were recovered following poisoning.

No tagged pumpkinseed sunfish that had been recaptured after tagging were recovered at the time of the removal of the fish population.

Movement of Fish in Third Sister Lake

From the data obtained by the recapture of tagged fish it was possible to trace the movement of individual fish to a limited extent. All fish tagged were released at the point of capture and the location, species, and the date of capture recorded. To facilitate the accurate

TABLE 1.—*Number of fish marked in 1939 and 1940 and percentages of marked fish recovered at time of poisoning*

Item	Bluegills		Bullheads		Bass		Pumpkinseed sunfish	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Number tagged (1939)	486	.....	69	.....	15	.....	53	.....
Number tagged (1940)	45	.....	26	.....	37	.....	18	.....
Number clipped (1939)	10	.....	14	.....	0	.....	1	.....
Number clipped (1940)	505	.....	68	.....	7	.....	41	.....
Number of 1939 tagged fish returned (in lake 18-24 months)	37	7.6	26	37.7	4	26.7	1	1.9
Number of 1940 tagged fish returned (in lake 8-12 months)	5	11.1	23	88.5	23	62.2	10	55.6
Number of clipped fish returned	184	37.8	51	62.2	2	28.6	2	4.7
Number of fish in lake when poisoned	[1]1,790	.....	[2]199	.....	[2]219	.....	[2]204	.....
Total tagged fish recovered	42	7.9	49	51.6	27	50.0	11	15.5

[1]Fish in size range of those tagged (over 3 inches total length).
[2]Fish in size range of those tagged (over 6 inches total length)

TABLE 2.—*Number of fish tagged and number of tagged fish recaptured by nets and hook-and-line in 1939, 1940*

Species	Number of fish tagged (1939)	Number recaptured (1939)	Percentage recaptured (1939)	Number of fish recaptured[1] (1940)	Percentage recaptured (1940)	Number of fish tagged (1940)	Number of fish recaptured[2] (1940)	Percentage recaptured[2] (1940)
Bluegill	486	28	5.7	20	4.1	45	2	4.4
Bullhead	69	23[3]	33.3	20[3]	29.0	26	12	46.3
Largemouth bass	15	0	0	4	26.7	37	5	13.5
Pumpkinseed sunfish	53	2	3.8	1	1.9	18	0	0

[1]Tagged in 1939.
[2]Tagged in 1940.
[3]Includes 7 fish taken both in 1939 and 1940.

location of the point of release of tagged fish and the point of recapture of these fish the shore line of the lake was divided into 100-foot sections and the limits of each section clearly marked. By this method it was possible to locate the point of capture and release of the fish within 10 yards. In calculating the movement of the fish in the lake only those fish that had been free in the lake at least 15 days following their capture and tagging were considered.

The evidence presented, when interpreted as an indication of fish movement in the lake, is subject to criticism. Although the number of returns was small the limited returns did indicate that many of the bluegills and bullheads have a tendency to remain in a limited area for a considerable length of time.

Movement of Bluegills

Table 3 is a summarization of the movements of the bluegills as interpreted from the tag returns. From this table it can be seen that approximately 60 per cent of the tag returns of bluegills were from within 30 yards of the point of original capture.

Movement of Bullheads

From Table 4 it can be seen that many of the bullheads evidenced a tendency to remain in one area over a considerable length of time, as more than 50 per cent of the recaptured bullheads were taken within 30 yards of the point of the original tagging. The bullheads were more readily captured by nets after tagging than were the bluegills and some of the bullheads were recaptured as many as six times during the two summers of the investigation.

Thirty-nine per cent of the bullheads recaptured after tagging were taken within 15 yards of the point of release following tagging, 81 per cent within 100 yards, and all of the bullheads recaptured more than once were taken at the same location each time, even though the intervals between captures were several weeks or months apart.

Table 3.—*Summary of movement of tagged bluegills in Third Sister Lake*

Number of fish recaptured[1]	Movement from point tagging (yards)	Time between tagging and recapture (days)	Percentage of fish recaptured
12	0	15-359	44
4	30	16-343	14.8
2	65	301-404	7.4
4	65-150	37-370	14.8
5	150+	20-394	18.5

[1]Includes only fish free in the lake more than 15 days after tagging.

Table 4.—*Summary of movements of bullheads in Third Sister Lake*

Number of fish recaptured[1]	Movement from point tagging (yards)	Time between tagging and recapture (days)	Percentage of fish recaptured
11	0	15-432	39
4	15-30	331-380	14
8	30-100	46-435	28.6
4	100+	350-457	14

[1]Includes only fish free in the lake more than 15 days after tagging.

Movement of Largemouth Bass

Fifty-two bass were tagged in 1939-1940 and of these, seven were returned by hook and line or in nets. The returns indicate that the bass roved over the entire lake and showed no tendency to remain in one location. The bass had a tendency to be retaken in the nets and of the seven returns, four were taken more than once and one was taken four times.

It seems possible that the bullheads and bass entered the nets in search of food as nearly every bullhead and bass taken in the nets was engorged with fish, more often than not with a bluegill as large as could be swallowed.

No other fish species was tagged and recaptured in numbers large enough to attempt any conclusions as to their movement in the lake.

Fish in the Lake Tagged Prior to this Investigation

Not included in any of the data in the tables concerning tagged and fin-clipped fish were 162 bluegills and 67 largemouth bass tagged in the summers of 1933 and 1935 by Dr. D. S. Shetter of the Institute for Fisheries Research staff, and 206 bluegills fin-clipped in 1937.

A different series of tag numbers and different combinations of fin-clipping were used during the course of the present experiment from those used by Dr. Shetter.

Fifteen (7.3 per cent) of the 206 fin-clipped bluegills marked in 1937 were recovered at the time of the poisoning. These fish were free in the lake 4 years prior to the poisoning of the lake.

Three (1.8 per cent) of the 162 bluegills tagged in 1933 and 1935 were recovered during the investigation. In Table 5 are shown the data concerning these three fish. From the table it can be seen that the growth rate for these fish was extremely low, being only slightly over one inch in more than 4 years for the bluegill and not quite two inches for the bass that was free in the lake nearly eight years after tagging.

Table 5.—*Growth rate of three tagged fish in Third Sister Lake*

Species	Date tagged	Date recovered	Length when tagged (millimeters)	Length when recovered (millimeters)	Growth (millimeters)	Time free in lake (months)
Bluegill	5-20-35	6-27-39	175	205	30	49
Largemouth bass	11-4-33	7-17-39	260	287	27	68
Do.	9-28-33	4-26-41	200	246	46	91

This slow growth cannot be attributed to their being members of an overcrowded and stunted fish population as the fish of the lake showed a normal growth rate for southern Michigan lakes, that is: the bass of the lake reached legal length (10 inches) in their third or early in their fourth year and bluegills reached legal length (6 inches) in their third growing season.

The tags on these three fish were in good condition, being only slightly corroded and the figures were clearly legible. The tags were not crowding the jaw bone and in all cases were imbedded in a gelatinous substance secreted by the lower jaw.

TABLE 6.—*The growth rate of tagged bluegills, bullheads, and largemouth bass in Third Sister Lake*

Species	Date tagged	Total length when tagged (millimeters)	Total length when recovered (millimeters)	Growth period[1] (months)	Total growth (millimeters)
Bluegills	6-30-39	200	206	22	6
	7-1-39	195	215	22	20
	7-6-39	212	212	22	0
	8-1-39	190	204	21	14
	8-1-39	180	194	21	14
	8-21-39	193	198	20	5
	8-23-39	200	200	20	0
	9-8-39	188	200	20	12
Bullheads	6-30-39	235	255	22	20
	6-30-39	248	272	22	24
	6-30-39	250	258	22	8
	7-1-39	250	270	22	20
	7-6-39	205	255	22	50
	6-16-39	205	213	22	8
	6-16-39	234	236	22	2
	7-9-39	240	263	22	23
	6-19-39	270	282	22	12
	7-20-39	285	287	21	2
	7-21-39	182	225	21	43
	7-22-39	230	240	21	10
	7-23-39	260	285	21	25
	7-27-39	182	249	21	67
	7-27-39	177	185	21	8
	8-3-39	255	272	21	17
	7-27-39	175	204	21	29
Largemouth bass	7-7-39	360	365	22	5
	8-5-39	205	226	21	11

[1]All fish recovered at time of poisoning of the lake—May 6, 1941.

GROWTH OF FISH TAGGED IN 1939-1940

Plans to record the length and weight of the fish tagged were abandoned when it was found that the additional handling necessary to obtain the data resulted in an increased mortality during the midsummer months. Of the fish that were measured when tagged 8 bluegills, 17 bullheads, and 2 bass were recovered following the poisoning of the lake. Table 6 shows the growth of these during the period they were tagged and free in the lake. The bluegills were nearly all in the same size range and show considerable variation in growth rate, the growth varying from 2 to 20 millimeters in approximately 22 months. The average growth was 9 millimeters.

The bullheads recovered were also in about the same size group and showed a large variation in growth, varying from 2 to 67 millimeters. The average growth was 22 millimeters.

One of the two measured bass recovered had grown 5 and the other 11 millimeters in 22 months.

Tagged Bullhead in Captivity

A bullhead tagged July 1, 1939 was removed from the lake 10 days following the first application of rotenone to Third Sister Lake on May 6, 1941. During the poisoning the fish had been confined in a cage suspended at a depth of 20 feet to test the toxicity of the water and following the completion of the test the fish was placed in an aquarium where it was held until it died of unnatural causes on March 15, 1943. At the time the bullhead was removed from the lake the tag encircling the lower jaw was showing signs of irritating the flesh. When the fish died the tag had nearly eroded through the jaw bone, there being only a very thin strip joining the point where the tag was placed. At no time during its captivity did the sore caused by the tag have any tendency to heal. This same condition was noted to a lesser extent in nearly all bullheads and to some extent in the bluegills and largemouth bass.

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APPENDICES

AMERICAN FISHERIES SOCIETY

Organized 1870

Certification of Incorporation

We, the undersigned, persons of full age and citizenship of the United States, and a majority being citizens of the District of Columbia, pursuant to and in conformity with sections 599 to 603, inclusive, of the Code of Law for the District of Columbia, enacted March 3, 1901, as amended by the acts approved January 31 and June 30, 1902, hereby associate ourselves together as a society or body corporate and certifying in writing:

1. That the name of the Society is the American Fisheries Society.

2. That the term for which it is organized is nine hundred and ninety-nine years.

3. That its particular business and objects are to promote the cause of fish culture; to gather and diffuse information bearing upon its practical success, and upon all matters relating to the fisheries; to unite and encourage all interest of fish culture and the fisheries; and to treat all questions of a scientific and economic character regarding fish; with power:

(a) To acquire, hold and convey real estate and other property, and to establish general and special funds.
(b) To hold meetings.
(c) To publish and distribute documents.
(d) To conduct lectures.
(e) To conduct, endow, or assist investigation in any department of fishery and fish-culture science.
(f) To acquire and maintain a library.
(g) And, in general, to transact any business pertinent to a learned society.

4. That the affairs, funds and property of the corporation shall be in general charge of a council, consisting of the officers and the executive committee, the number of whose members for the first year shall be seventeen, all of whom shall be chosen from among the members of the Society.

Witness our hands and seals this 16th day of December, 1910.

Seymour Bower	(Seal)
Theodore Gill	(Seal)
William E. Meehan	(Seal)
Theodore S. Palmer	(Seal)
Bertrand H. Roberts	(Seal)
Hugh M. Smith	(Seal)
Richard Sylvester	(Seal)

Recorded April 16, 1911.

CONSTITUTION AND BY-LAWS

OF THE

AMERICAN FISHERIES SOCIETY

(As Amended August 26, 1941)

ARTICLE I

NAME AND OBJECT

The name of the Society shall be the American Fisheries Society.

The objects of the Society shall be to promote the cause of fish culture and its allied interests; to gather and diffuse information on all questions pertaining to fish culture, fish, and fisheries; and to unite and encourage those interested in fish culture, and fisheries problems.

ARTICLE II

MEMBERSHIP

The membership of this Society shall be classified as follows: Active, Club, Libraries, State, Patron, Honorary, and Corresponding.

Active Members.—Any person may upon a two thirds vote of the members present at any regular annual meeting and upon the payment of one year's dues become an active member of this Society. The annual dues of active members shall be three ($3.00) dollars per year, payable in advance. Any active member may upon payment of fifty ($50.00) dollars become exempt from the payment of annual dues though retaining the privilege of active membership for the dura tion of his life.

Club Members.—Any sporting or fishing club or society, or any firm or corporation, upon a two thirds vote of the members present at any regular meeting and upon the payment of one year's dues, may become a club member of this Society. The annual dues of club members shall be five ($5.00) dollars per year.

Libraries.—Libraries may be admitted to membership upon a two thirds vote of the members present at any regular meeting and the payment of one year's dues. The annual dues for libraries shall be two ($2 00) dollars per year.

State Memberships.—Any state, provincial or federal department of the United States, Canada or Mexico may become a state member of this Society upon a two-thirds vote of the members present at any regular meeting and the payment of one year's dues. The annual dues for State membership shall be twenty ($20.00) dollars per year.

Patrons.—Any person, society, club, firm or corporation, on approval of the Executive Committee and the payment of fifty ($50.00) dollars or more, may become a patron, and shall be listed in all the published membership lists of the Society.

Honorary and Corresponding Members.—Any person may be made an honorary or corresponding member of this Society upon a two thirds vote of the members present at any regular annual meeting of the Society. The President of the United States, the President of Mexico, the Governors of the several states, and the Secretary of the Interior of the United States, the Governor General of Canada, the Lieutenant-Governors of the several Canadian provinces, and the Dominion

Minister in Charge of Game and Fisheries shall be honorary members of this Society while occupying their respective official positions.

Election of Members between Annual Meetings.—The President, Secretary and Treasurer of the Society are hereby authorized to act upon all applications for memberships received while the Society is not in session.

Rights and Duties of Members.—Active members in good standing only shall have the right to vote at regular or special meetings of the Society. Any member is held to be in good standing whose dues are not more than one year past due. In case of non-payment of dues for one year, proper notice shall be given the member by the Treasurer in writing, and if such member remains delinquent one month from the date of such notice, his name shall be dropped from the roll of the Society. Such delinquent member, having been dropped for non-payment of dues, shall be ineligible for election as a new member for a period of one year, except upon payment of arrears and current dues.

Transactions.—Each member of the Society in good standing, except honorary members, shall receive one copy of the annual volume of *Transactions.* Only members in good standing may present papers either by reading or by title at the annual meetings and publish them in the *Transactions;* except that outstanding non members invited by the President of the Society to participate in the program shall be exempted from this requirement. No member may have listed on the program of an annual meeting, or present, or have published in any one volume of the *Transactions* more than two papers: and for purposes of this rule joint authorships shall compare equally with sole authorships.

Quorum.—Twenty voting members shall constitute a quorum for the transaction of business at annual or other meetings of the Society.

ARTICLE III

Funds

Current Fund.—All moneys received from the payment of dues of active members, club members, libraries, life members, state members, sale of *Transactions,* contributions thereto, and from any miscellaneous sources, shall be credited to the Current Fund of the Society and shall be paid out only on vouchers regularly approved by the President and Secretary.

Permanent Fund.—The President, Secretary and Treasurer shall be the Trustees of the Permanent Fund. All moneys received from patrons, bequests, and contributions thereto shall be credited to the Permanent Fund of the Society. Such fund shall be invested by the Treasurer in such manner as may be approved by the trustees of such fund. The members of the Society shall, at each annual meeting, determine the disposition of interest accruing from such investment.

ARTICLE IV

Officers

The officers of this Society shall be a president, a first vice president, and a second vice president, all of whom shall be elected for the term of one year and shall be ineligible for reelection to the same office until a year after the expiration of their terms; a secretary, a treasurer, a librarian, and five vice presidents, one to be in charge of each of the following divisions or sections:

1. Fish Culture.
2. Commercial Fishing.
3. Aquatic Biology and Physics.
4. Angling.
5. Protection and Legislation.

The officers specified above, and the president of the previous year, shall form an Executive Committee* with authority to decide the policies of the Society and to transact such business of the Society as may be found necessary. The Executive Committee is authorized to fill from the membership any vacancies that may occur in any offices between meetings. A majority of the Executive Committee shall constitute a quorum.

Only members in good standing who are in attendance or have been in attendance at one of the two immediately preceding meetings shall be eligible for election to the offices listed above and for appointment to any committee, except the members of the Committee on Common and Scientific Names of Fishes.

The officers shall be elected by a majority vote at a regular meeting, a quorum being present.

No officer of this Society shall receive any salary or compensation for his services and no allowances shall be made for clerical services except by vote of the Society at regular annual meetings.

Duties of Officers.—The President shall preside at the regular and all special meetings of the Society and shall be ex-officio chairman of the Executive Committee.

The first Vice-President shall act in the place of the President in case of absence or inability of the latter to serve.

The Secretary shall keep the records of the Society, conduct its correspondence, promote its membership, and arrange for regular and special meetings. The Secretary shall also attend to the publication and distribution of the annual issuance of Transactions.

The Treasurer shall receive and collect all dues and other income of the Society, shall have the custody of its funds and pay all claims which have been duly approved. The Treasurer shall furnish a bond in the sum of seven thousand, five hundred ($7,500) dollars to be approved by the Executive Committee and to be paid for by the Society. The offices of Secretary and Treasurer may be occupied by the same person.

The Librarian shall have the custody of the library of the Society, including its permanent records and printed *Transactions*, and shall have charge of the sale of surplus copies of such *Transactions*.

The Vice-President of each division shall become conversant with the subject of his division and present a report on it at the regular meeting, placing emphasis upon developments during the past year.

Committee members shall cooperate in performing the functions of their appointments and render reports as directed by the President.

ARTICLE V

Standing Committees

The standing committees shall be Executive; International Relations; State and National Relations; Common and Scientific Names of Fishes; and Publications. The Committee on Publications shall be appointed by the President. The Executive Committee shall be selected as provided for by Article IV.

The Committee on International Relations shall be composed of seven members selected by the nominating committee for election, and its duties shall be to exchange ideas pertaining to the various phases of fisheries administration, biology, including fish culture, with foreign fishery biologists, conservation and fishery administration officials, fish-culturists or aquicultural societies. A report based on such exchange should be presented at each regular meeting.

The Committee on State and National Relations shall be composed of five members selected by the nominating committee for election, and its duties shall be to act in behalf of the Society as a coordinating and advisory board for the

*The Council was discontinued and the Executive Committee enlarged by Amendment to By-Laws, September 11, 1935.

consideration of interstate and National-State fishery problems. A report shall be presented at each annual meeting.

The Committee on Common and Scientific Names of Fishes shall be composed of seven members selected by the nominating committee for election. Its duties shall be to establish and maintain in the files of the Librarian of this Society a correct check list of the species of fishes occurring in the waters of the United States and Canada. This list should contain both scientific and common names.

The Committee on Publications shall be composed of five members, and its duties shall be to select and edit manuscripts submitted for publication. Papers shall be submitted ready for publication within thirty days after the close of the regular meeting. Such papers, together with the minutes of the regular and special meetings and the reports of the various divisions and committees, shall be published in an annual volume which shall be numbered in series with previous volumes and entitled: TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY.

ARTICLE VI

Meetings

The regular meeting of the Society shall be held once a year, the time and place to be decided upon at the preceding meeting, or, in default of such action, by the Executive Committee. Special meetings shall be called by the President upon approval of a majority of the Executive Committee.

ARTICLE VII

Order of Business

1. Call to order by the President.
2. Roll call of members.
3. Application for memberships.
4. Reports of officers:
   a. President
   b. Secretary
   c. Treasurer
   d. Vice-Presidents of Divisions
   e. Standing Committees
   f. Special Committees
5. Committees appointed by the President:
   a. Committee of five on nomination of officers and standing committees for the ensuing year.
   b. Committee of five on time and place of next meeting.
   c. Committee of five on resolutions.
   d. Auditing committee of three.
   e. Committee of three on program.
   f. Committee of three on publicity.
   g. Committee of five on publications.*
6. Reading of papers and discussions of same. In the reading of papers preference shall be given to the members present.
7. Miscellaneous business.
8. Adjournment.

ARTICLE VIII

Changing By-Laws

The By-Laws of the Society may be amended, altered or repealed by a two-thirds vote of the members present at any regular meeting, provided at least twenty-five members are present at said regular meeting.

*A resolution adopted August 24, 1937 established a staggered committee of five and provided that each incoming President shall appoint one new member for a term of five years and designate the Chairman of the Committee.

AMERICAN FISHERIES SOCIETY

LIST OF MEMBERS

(Showing year of election to membership)

In accordance with the policy determined by the Executive Committee, no members have been dropped for non-payment of dues during the war period. All members on the rolls of the Society in 1942 have been retained. Members who have not paid their dues during this period and members for whom no satisfactory address is on file, have been starred in the list which follows.

The Secretary is anxious to publish a membership list in the next Volume giving correct addresses for all members in good standing at that time. If your name is starred in this list, please communicate with the Secretary giving your present address. It will be appreciated also if you will send the correct address for any other member not properly listed below.

HONORARY MEMBERS

The President of the United States of America.
The President of the United Mexican States.
The Secretary of the Interior of the United States of America.
The Governors of the several States.
The Governor-General of Canada.
The Lieutenant-Governors of the several Canadian Provinces.
The Canadian Minister of Fisheries.
'08 Antipa, Prof. Gregoire, Inspector-General of Fisheries, Bucharest, Roumania.
'06 Besana, Giuseppe, Lombardy Fisheries Society, Via Rugabello 19, Milan, Italy.
'09 Blue Ridge Rod and Gun Club, Harpers Ferry, W. Va.
'04 Denbigh, Lord, London, England.
'40 Gordon, Seth, % Game Commission, Harrisburg, Pa.
'09 Nagel, Hon. Chas., St. Louis, Mo.
'08 Nordqvist, Dr. Oscar Fritjof, Superintendent of Fisheries, Lund, Sweden.

PATRONS

'14 Alaska Packers Association, San Francisco, Calif.
'15 Allen, Henry F. (Agent Crown Mills), 210 California St., San Francisco, Calif.
'15 American Biscuit Co., 815 Battery St., San Francisco, Calif.
'15 American Can Co., Mills Building, San Francisco, Calif.
'15 Armour & Co., Battery and Union Sts., San Francisco, Calif.
'15 Armsby, J. K., Company, San Francisco, Calif.
'15 Atlas Gas Engine Co., Inc., Foot of 22nd Avenue, Oakland, Calif.
'15 Balfour, Guthrie & Co., 350 California St., San Francisco, Calif.
'15 Bank of California, N. A., California and Sansome Sts., San Francisco, Calif.

'15 Bloedel-Donovan Lumber Mills, Bellingham, Wash.
'15 California Barrel Co., 22d and Illinois Sts., San Francisco, Calif.
'15 California Door Co., 43 Main St., San Francisco, Calif.
'15 California Stevedore & Ballast Co., Inc., 210 California St., San Francisco, Calif.
'15 California Wire Cloth Company, San Francisco, Calif.
'15 Caswell, Geo. W., Co., Inc., 503-4 Folsom St., San Francisco, Calif.
'15 Coffin-Redington Co., 35-45 Second St., San Francisco, Calif.
'15 Columbia River Packers Association, Astoria, Ore.
'15 Crane Co., C. W. Weld, Mgr., 301 Brannon St., San Francisco, Calif.
'15 First National Bank of Bellingham, Bellingham, Wash.
'15 Fuller, W. P., & Co., 301 Mission St., San Francisco, Calif.
'15 Grays Harbor Commercial Co., Foot of 3d St., San Francisco, Calif.
'15 Jones-Thierbach Co., The, Battery and Merchant Sts., San Francisco, Calif.
'15 Knapp, The Fred H., Co., Arcade-Maryland Casualty Building, Baltimore, Md.
'15 Linen Thread Co., The, W. A. Barbour, Mgr., 443 Mission St., San Francisco, Calif.
'15 Morrison Mill Co., Inc., Bellingham, Wash.
'15 Morse Hardware Co., Inc., 1025 Elk St., Bellingham, Wash.
'15 Pacific Hardware & Steel Co., 7th and Townsend Sts., San Francisco, Calif.
'15 Pacific States Electric Co., 575 Mission St., San Francisco, Calif.
'15 Pope and Talbot, Foot of 3d St., San Francisco, Calif.
'15 Puget Sound Navigation Co., Seattle, Wash.
15 Ray, W. S. Mfg. Co., Inc., 216 Market St., San Francisco, Calif.
'15 Schmidt Lithograph Co., 2d and Bryant Sts., San Francisco, Calif.
'15 Schwabacher-Frey Stationery Co., 609-11 Market St., San Francisco, Calif.
'15 Sherwin-Williams Co., The, 454 Second St., San Francisco, Calif.
'15 Ship Owners' and Merchants' Tug Boat Co., Foot of Green St., San Francisco, Calif.
'15 Smith Cannery Machine Co., 2423 South First Avenue, Seattle, Wash.
'15 Standard Gas Engine Co., Dennison and King Sts., Oakland, Calif.
'15 Standard Oil Co. of California, Standard Oil Building, San Francisco, Calif.
'15 U. S. Rubber Co. of California, James B. Brady, Gen. Mgr., 2nd and Folsom Sts., San Francisco, Calif.
'15 U. S. Steel Products Co., Rialto Building, San Francisco, Calif.
'15 Wells Fargo National Bank of San Francisco, Montgomery and Market Sts., San Francisco, Calif.
'15 Western Meat Co., 6th and Townsend Sts., San Francisco, Calif.
'15 White Bros., 5th and Brannon Sts., San Francisco, Calif.

LIFE MEMBERS

'00 Beeman, Henry W., New Preston, Conn.
'13 Belding, Dr. David L., 80 East Concord St., Boston, Mass.
'80 Belmont, Perry, 1618 New Hampshire Ave., Washington, D. C.
'97 Birge, Dr. E. A., University of Wisconsin, Madison, Wis.
'42 Brown, Louis P., Insurance Bldg., Glens Falls, N. Y.
'04 Buller, A. G., Pennsylvania Fish Commission, Corry, Pa.
'12 Buller, Nathan R., Pennsylvania Fish Commission, Harrisburg, Pa.
'26 Cary, Guy, 55 Wall St., New York, N. Y.
'04 Coker, Dr. Robert E., University of North Carolina, Chapel Hill, N. C.
'01 Dean, Herbert D., Northville, Mich.
'15 Folger, J. A., Howard and Spencer Sts., San Francisco, Calif.
'12 Fortmann, Henry F., 1007 Gough St., San Francisco, Calif.
'22 Grammes, Charles W., Hamilton Park, Allentown, Pa.
'03 Gray, George W., Marine Biological Laboratory, Woods Hole, Mass.
'28 Hall, W. A., Co., Gardiner, Mont.
'10 Hopper, George L., Havre De Grace, Md.
'43 Hunter, Dr. R. P., 491 Wells Rd., Wethersfield, Conn.
'23 Kienbusch, C. O., 12 E. 74th St., New York, N. Y.
'22 Kulle, Karl C., Suffield, Conn.
'26 Lackland, Sam H., 69 So. Ann St., Mobile, Ala.
'26 Low, Ethelbert I., 256 Broadway, New York, N. Y.
'43 McConica, Dr. T. H., III, 612 E. Ellsworth St., Midland, Mich.
'15 Mailliard, Joseph, 1815 Vallejo St., San Francisco, Calif.
'99 Morton, W. P., 105 Sterling Ave., Providence, R. I.
'16 Nelson, Charles A. A., Lutsen, Minn.
'07 Newman, Edwin A., 4205 8th St., N. W., Washington, D. C.
'31 Nicholas, E. Mithoff, 20 S. 3d St., Columbus, Ohio.
'10 Osburn, Prof. Raymond C., Ohio State University, Columbus, Ohio.
'04 Palmer, Dr. Theodore S., 1939 Biltmore St., N. W., Washington, D. C.
'10 Radcliffe, Dr. Lewis, 5600 32nd St., N. W., Washington, D. C.
'43 St. Bernard Fish & Game Club, St. Alexis des Monts, P. Q., Canada.
'13 Timson, William, Alaska Packers' Association, San Francisco, Calif.
'11 Valette, Luciano H., Echevarria F. C. S., Buenos Aires, Argentina, S. A.
'22 Walcott, Frederic C., Norfolk, Conn.
'98 Ward, Dr. Henry B., 1201 Nevada St., Urbana, Ill.
'97 Wood, Colburn C., Box 355, Plymouth, Mass.

ACTIVE MEMBERS

'13 Adams, William C., 55 South Lake Ave., Albany 3, N. Y.
'29 Ainsworth, A. L., Tuxedo Fisheries, Tuxedo Park, N. Y.
'44 Alcorn, Joseph R., R F.D. No. 1, Box 19A, Fallon, Nev.
'39 Alderson, I. T., Von Hoffman Press, 101 S. 9th St., St. Louis, Mo.
'32 Aldrich, A. D., P.O. Box 1365, Tulsa, Okla.
'35 Alexander, George J., Parliament Bldg, Victoria, B. C., Canada.
'37 Allen, Edward W., Northern Life Tower, Seattle, Wash.
'29 Allen, William Ray, Dept. of Zoology, Univ. of Kentucky, Lexington, Ky.
'43 Allison, Leonard N., Pittsburgh Rd., Poland, Ohio.
'08 Anderson, August J., Box 704, Marquette, Mich.
'41 Anderson, Bertil G., Franz Theodore Stone Laboratory, Put-in-Bay, Ohio.
'43 Anderson, William W, 1609 Masonic Temple Bldg., New Orleans, La.
'24 Annin, Harry K., Spring St., Caledonia, N. Y.
'14 Annin, Howard, Van Cortland Ave., Ossining, N. Y.
'29 Atkinson, C. J., Fisheries Dept., Ottawa, Canada.
'33 Baer, Harry D., Box 200, Coleman Station, Anderson, Calif.
'37 Bailey, Dr Reeve M., University of Michigan, Ann Arbor, Mich.
'33 Bailliere, Lawrence, Stoutland, Mo.
'37 Baker, Dr. Clinton L., c/o Southwestern, Memphis, Tenn.
'15 Balch, Howard K., 110 E. Seeboth St., Milwaukee, Wis.
'38 Ball, Robert C., University Museums Annex, Ann Arbor, Mich.
'23 Bangham, Dr. Ralph V., Wooster College, Wooster, Ohio.
'05 Barbour, Prof Thomas, Museum of Comparative Zoology, Cambridge, Mass.
'40 *Barrett, Paul H., 623 Kensington Rd., East Lansing, Mich.
'43 Bayliff, William H., State Office Bldg., Annapolis, Md.
'34 Beech, U. Sidney, Highland, Mich.
'43 Beal, Henry J., Hon., Court House, Omaha, Nebr.
'38 *Beckman, William, University of Museums Annex, Ann Arbor, Mich.
'40 *Beddow, William D., Hempstead High School, Hempstead, N. Y.
'38 Bennett, Dr. George W., Illinois Natural History Survey, Urbana, Ill.
'40 *Berrian, William, Copco, Calif.
'38 Berube, Louis, School of Fisheries, Ste. Anne de la Pocatiere, P. Q., Canada.
'38 Bickelhaupt, F. R., Lakefield Farm, Burton, Ohio.
'27 Birdseye, Clarence, General Seafoods Corp., Gloucester, Mass.
'35 Bishop, Sherman C., University of Rochester, Rochester, N. Y.
'42 *Bjerkness, K. K, 1570 West 34th St., Vancouver, B. C., Canada.
'42 Blair, A. A., Fishery Research Laboratory, St. John's, Newfoundland.
'40 Bode, I. T., Conservation Commission, Jefferson City, Mo.
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'44 Bond, Horace P., 121 Grant St., Bangor, Me.
'39 Bonham, Kelshaw, 5240 18th Ave., N. E, Seattle 5, Wash.
'00 Bower, Ward T., Fish & Wildlife Service, Merchandise Mart, Chicago 54, Ill.
'42 *Brashears, Robert L., James Springs, N. M.
'20 Breder, Dr C. M., Jr., American Museum of Natural History, New York, N. Y.
'44 Briggs, John C., 1163 Van Buren St., Corvallis, Ore.
'35 Brown, Dr. C. J. D., 2725 Montlake Blvd., Seattle 2, Wash.
'30 Brown, Major James, Department of Conservation, New Orleans, La.
'44 Bryan, Paul, R.F.D. No. 1, Decatur, Ala.
'20 Buller, C. R., Pleasant Mount, Wayne Co., Pa.
'39 *Burghduff, A. E., Ferry Building, San Francisco, Calif.
'40 *Burrows, Roger E., Fish & Wildlife Service, Leavenworth, Wash.
'30 Butler, George E., 311 Kingston Crescent St., Vital, Manitoba, Canada.
'27 Cable, Louella E., 4810 Fox St., Daniel's Park, Berwyn, Md.

'40 Calhoun, Alexander J., Division of Fish & Game, Sacramento, Calif.
'41 Campbell, Charles J., Hillsdale, Ore.
'44 Cannady, Bruce B., U S. Fisheries Station, Anderson, Calif.
'36 Carbine, William F., U. S. Fish and Wildlife Service, c/o American Embassy (Manila), A.P.O. 900, c/o Postmaster, San Francisco, Calif.
'43 Carlander, Kenneth D., Department of Conservation, St. Paul, Minn.
'42 *Carr, Harold B., Civil Aeronautics Board, Earle Bldg., Washington, D. C.
'39 *Chamberlain, Thos. Knight, 254 F. E., College Station, Tex
'42 *Chisholm, W. F., P.O. Box 9055, University Branch, Baton Rouge, La.
'44 Churchill, Warren S., State Fish Hatchery, Woodruff, Wis.
'29 Chute, Walter H., Director, John G. Shedd Aquarium, Grant Park, Chicago, Ill.
'41 *Clark, Dr Ernest D., 826 Skinner Bldg., Seattle 1, Mich.
'37 Clark, O. H., Jr., R. R. No. 4, Ann Arbor, Mich.
'44 Cleaver, Fred C., 2209 W. 75th St., Seattle, Wash.
'21 Clemens, Dr. Wilbert A., University of British Columbia, Vancouver, B C., Canada.
'00 Cobb, Eben W., 1180 Delaware Ave., St. Paul, Minn.
'35 Cobb, Kenneth E., Windsor Locks, Conn.
'17 Cook, Ward A., U. S. Fish & Wildlife Service, Duluth, Minn.
'41 *Cooper, Edwin L., University Museums Annex, Ann Arbor, Mich.
'34 Cooper, Dr. Gerald P., University Museums Annex, Ann Arbor, Mich.
'34 Corcoran, John P., Box 4066, University Sta., Tucson, Ariz.
'38 Cox, Harry B., Fish & Wildlife Service, Fisheries Station. Birdsview. Wash.
'41 Cramer, Frederick K., North Rotunda Bldg., Stanford University, Calif.
'13 Crandall, A. J., Ashaway Line & Twine Mfg Co., Ashaway, R. I.
'34 *Croker, Richard, State Fisheries Laboratory, Terminal Island, Calif.
'28 Crosby, Col. W. W., 1040 Adella Ave., Coronado, Calif.
'08 Culler, Capt., C. E., Fish & Wildlife Service, Plymouth Bldg., Minneapolis, Minn.
'37 Curran, Dr H. Wesley, Queen's University, Kingston, P. Q., Canada.
'34 Curtis, Brian C., Dr., Ferry Bldg., San Francisco, Calif.
'35 Davis, George Wm., Fish & Game Service, Montpelier, Vt.
'23 Davis, Dr. H. S., 616 Oregon Bldg., Portland, Ore.
'40 *Day, Albert M., Fish & Wildlife Service, Dept. of the Interior, Washington 25, D C.
'26 *Day, Harry V., 510 Park Ave., New York, N. Y.
'34 Deason, Dr. H. J., Fish & Wildlife Service, Dept. of Interior, Washington 25, D. C.
'27 DeBoer, Marston J., Department of Conservation, Lansing, Mich.
'25 DeCozen, Alfred, 970 Broad St., Newark 2, N J.
'44 *Degani, S/Sgt. John G., Fort Sumner, N. M.
'41 DeGruchy, James, 1017 Chester St., Stillwater, Okla.
'41 DeLacy, Allan C., Fisheries Hall No. 2, Univ. of Washington, Seattle 5, Wash.
'38 *Delisle, Henry A., U. S Fish & Wildlife Service, Berlin, N. H.
'24 Dence, Wilford A., New York State College of Forestry, Syracuse 10, N. Y.
'44 Dendy, Jack S., TVA, Norris, Tenn.
'19 Denmead, Talbott, 2830 St. Paul St., Baltimore, Md.
'43 *Dickensen, V. L., Wisconsin Conservation Commission, Augusta, Wis.
'39 Dill, William A, California Division of Fish & Game, Fresno, Calif.
'43 *Dimick, Roland E., Oregon State College, Corvallis, Ore.
'43 *Doan, Kenneth H., Stone Laboratory, Put-in-Bay, Ohio.
'35 Donaldson, Dr. Lauren R., University of Washington, Seattle, Wash.
'36 Doudoroff, Dr. Peter, Box 9055, University Branch, Baton Rouge, La.
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'28 Dunlop, Henry A., University of Washington, Seattle, Wash.
'41 *Earnest, Don, Bothell, Wash.
'44 Eggleton, Frank E., Zoology Department, University of Michigan, Ann Arbor, Mich.
'42 *Ellis, James N., University of Washington, Seattle, Wash.
'35 Erkkila, Leo, P.O. Box 89, Woodland, Calif.
'42 *Eschmeyer, Paul H., State Fish Hatchery, Watersmeet, Mich.
'33 Eschmeyer, Dr. R. William, TVA, Norris, Tenn.
'04 *Everman, J. W., Supervisor of Public Utilities, Dallas, Tex.
'36 Ivins, Donald, Box 1116, Westwood, Calif.
'28* Fearnow, Theodore C., Box 252, Berkeley Springs, W. Va.
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'32 Fish, Dr. Frederic F., Oregon State College, Corvallis, Ore.
'43 *Flanigon, Thomas H., University of Wisconsin, Madison, Wis.
'36 *Foster, C. R., Box 344, Tacoma, Wash.
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'24 *Frantz, Horace G., Salida, Colo
'38 Fremont, Charles, Dept. of Colonization, Mines & Fisheries, Quebec, Canada.
'36 *Fruchter, N., Box 1, R. 1, Anderson, Calif.
'43 Fuller, Arno C., P.O. Box 708, Uvalde, Tex.
'40 Funk, John, University of Missouri, Columbia, Mo.
'42 Furst, S. Dale, Jr., Box 478, Williamsport 61, Pa
'39 *Gambrell, Roy, Fort Worth Army Air Field, Fort Worth, Tex.
'38 Gaver, L. W., Grangeville, Idaho.
'41 *Gentry, Glen, Whiteville, Tenn.
'36 Goldie, Dr. William, 86 College St., Toronto, Canada.
'27 Gordon, Seth, Pennsylvania Game Commission, Harrisburg, Pa.
'38 Gottschalk, John, U. S. Fish and Wildlife Service, Billings, Mont.
'28 Grammes, J. Frank, 1119 Linden St., Allentown, Pa.
'43 Green, H. D., "The Cottage Tathhill," Dunfrieshire, Scotland.
'38 Greenbank, John, 603 South 7th St., La Crosse, Wis.
'29 Greene, Dr. C. Willard, New York State Conservation Dept., Albany, N. Y.
'43 *Grossman, Harold, Fawn River State Fish Hatchery, Orland, Ind.
'38 Gutermuth, C. R., American Wildlife Institute, Washington 5, D. C.
'39 Gutsell, Dr. James S., Fish & Wildlife Service, Kearneysville, W. Va.
'26 Halferty, G. P, 513 Coleman Bldg., Seattle 4, Wash.
'42 *Hammer, Ralph C., Chesapeake Biological Laboratory, Solomons Island, Md.
'10 Hansen, Ferdinand, 480 Lexington Ave., New York, N. Y.
'28 Harkness, Dr. William J. K., University of Toronto, Toronto, Canada.
'44 Harry, George Y., Jr., 6239 N. Delaware Ave., Portland 11, Ore.
'42 Harry, W. Bregy, Anthony Ave., R.F.D. No. 1, Newtown Square, Pa.
'35 Haskell, David C., 905 Brandywine Ave., Schenectady 8, N. Y.
'44 Haskell, William L., Box 4144, Los Angeles 24, Calif.
'42 Hasler, Dr. Arthur D., University of Wisconsin, Madison, Wis.
'34 Hawes, Hon. Harry B., Transportation Bldg., Washington 6, D. C.
'39 *Hayes, Elgin W., R. R. No. 6, Pembroke, P. Q., Ontario, Canada.
'04 *Hayford, Charles O., State Fish Hatchery, Hackettstown 275, N. J.
'36 Hazard, T. P., Peace Dale, R. I.
'28 Hazzard, Dr. A. S., 1015 Packard St., Ann Arbor, Mich.
'39 Heacox, Cecil, University of Rochester, Rochester, N. Y.
'43 *Height, Leon H., Jr., 1405 Fourth Ave., Spring Lake, N. J.
'41 Henn, Dr. Andrew W., Carnegie Museum, Pittsburgh, Pa.
'44 *Herman, Elmer, Southern Fisheries Area Headquarters, Route 3, Madison, Wis.
'43 *Herman, Raymond E., 10 South LaSalle St., Chicago, Ill.

'33 Herrington, William C., Natural Resources Section, SCAP-GHQ, APO 500, c/o Postmaster, San Francisco, Calif.
'40 Hess, A. D., TVA, Wilson Dam, Ala.
'34 Hewitt, Edward R., 127 East 21st St., New York, N. Y.
'40 Hewitt, Harold H., Burney Creek Hatchery, Burney, Calif.
'44 *Hiland, Robert M., U. S. Fish & Wildlife Service, Tishomingo, Okla.
'15 Hildebrand, Dr. Samuel F., 1528 Otis St., N. E., Washington, D. C.
'33 Hile, Dr. Ralph, University Museums, Ann Arbor, Mich.
'39 Hills, A. P., Box 225, Customs House, St. Johns, N. B., Canada.
'23 Hogan, Joseph R., State Fisheries, Lonoke, Ark.
'20 *Hoofnagle, G. W., Fishery Station, Leadville, Colo.
'38 *Holland, R. P., 180 Gaylor Rd., Scarsdale, N. Y.
'34 Hosley, N. W., Connecticut State College, Storrs, Conn.
'42 *Howell, Henry H., Box 404, Decatur, Ala.
'20 Hubbs, Dr. Carl L., Scripps Institution of Oceanography, LaJolla, Calif.
'43 *Huffman, Edward B., R.F.D. No. 4, Box 659-D, Akron, Ohio
'13 Huntsman, Dr. A. G., University of Toronto, Toronto, Canada.
'37 Inland Fisheries Officer, P. O. Box 389, Pietermaritzburg, Natal, South Africa.
'44 *Institute of Biology, University of Montreal, Montreal, Canada.
'33 Jackson, Charles E., National Fisheries Institute, Victor Bldg., Washington 1, D. C.
'44 Jacobson, J. R., 1118 Harrison St., Superior, Wis.
'39 *Jacocks, West, 201 Consolidated Bldg., Jacksonville 2, Fla.
'28 James, Milton C., Fish & Wildlife Serv , Dept. of the Interior, Washington 25, D. C.
'33 Jobes, Frank W., University Museums Bldg., Ann Arbor, Mich.
'41 Johnson, Bernard W., Como Bluff Hatchery, Rock River, Wyo.
'41 Johnson, Raymond E., Dr., 53 East Main St., Mystic, Conn.
'40 *Jones, Alden M., 317 Kirsch Dr , Syracuse 8, N. Y.
'18 Kauffman, R. M., "The Star," Washington 4, D. C.
'26 Kaul, William, Saint Mary's, Pa.
'44 *Kelly, Homer F., U. S. Fish & Wildlife Service, Anderson, Calif.
'28 Kemmerich, Alphonse, 600 Weatherly Bldg., Portland, Ore.
'12 Kemmerick, Joseph, P. O Box 232, Sedro-Wolley, Wash.
'41 Kennedy, W. A., 212 Pinedale Ave., St. Boniface, Manitoba, Canada.
'41 *Kibbe, T. S., Box 1306, Albuquerque, N. M.
'38 *King, Willis, Department of Conservation, Raleigh, N. C.
'33 *Kingsbury, Oliver R., 83 Crescent Dr., Albany 3, N. Y.
'24 Kitson, James A., 20 Somerset Ave., Boston, Mass.
'38 Klak, George E., 8101 Diggs Rd., Norfolk 5, Va.
'44 *Knowlden, Paul A., 525 Powhatan Place, Washington 11, D. C
'35 Koster, William J., University of New Mexico, Albuquerque, N. M.
'43 Krumholz, Louis A., Indiana University, Bloomington, Ind.
'33 Kuehl, Eric O., Fish & Wildlife Service, Underwood, Wash.
'42 Kurrus, Theodore, Dutchess Valley Club, Pawling, N. Y.
'37 Lagler, Dr. Karl F., University Museums, Ann Arbor, Mich.
'44 *Lambert, Ray B., Box 190, Port Clinton, Ohio.
'25 Langlois, Dr. T. H., P. O. Box C., Put-in-Bay, Ohio.
'40 Lapp, Harvey E., Poughquag, N. Y.
'29 Larsen, Henry A., Osceola, Wis.
'44* Laughlin, Llewellyn B., State Fish Hatchery, Woodruff, Wis.
'41 *Lawrence, William M., Wildlife Research Center, Delmar, N. Y.
'08 *Lay, Charles E., Railroad St., Ft. of Wayne St., Sandusky, Ohio.
'43 *Laythe, Leo L., 600 Weatherly Bldg., Portland, Ore.
'19 LeCompte, E. Lee, 512 Munsey Bldg., Baltimore, Md.
'25 Leim, Dr. A. H., Box 254, St Andrews N. B., Canada.
'35 Leonard, Justin W., University Museums Annex, Ann Arbor, Mich.

'36 Lewis, R. C., Hot Creek Rearing Ponds, Bishop, Calif.
'33 Lindner, Milton J., American Embassy, Mexico, D. F.
'43 *Lipschitz, Irving, University Museums, Ann Arbor, Mich.
'38 Lloyd, Charles N., Conservation Department, Spooner, Wis
'44 Lockley, A. S., c/o Dr. Carl L. Hubbs, Scripps Institute, LaJolla, Calif.
'43 *Lyman, Dr. F. Earle, 42 Hilldale Dr., Decatur, Ga.
'38 Lynch, James E., University of Washington, Seattle, Wash.
'44 McCabe, Britton, Springfield College, Springfield 9, Mass.
'44 *McConnell, James N., 126 Civic Court Bldg., New Orleans, La.
'27 McCay, Dr. C. M., Cornell University, Ithaca, N. Y.
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(REVISED 1946)

Please check each item below before the final typing of your manuscript and help your Society reduce the costs of publication, save your Editorial Board (which works gratis) much needless work, time, and expense, and avoid delay in the publication of the *Transactions*.

The following instructions were not drawn up arbitrarily but were condensed from the regulations contained in the best style manuals (Government Printing Office Style Manual; University of Chicago Style Manual). Certain instructions may appear unnecessary, but they are nevertheless essential for the proper handling of materials by the printer and the editor.

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REPORT ON THE DISEASES OF BROOK TROUT

JOHN EDWARD DOE

Department of Conservation, Lansing, Michigan

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DOE, JOHN C., J. W. BROWN, and H. W. GREEN.
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Item	Number of fish	Percentage of total	Average length in millimeters	Months	Cost of diet per pound
Brook trout surviving experiment No. 2	23	5.8	6.5	April-September	$0.25

12. **Capitals.** Capitalize words when used as part of a proper name or of an identifying number or letter, or when referring to a particular State, Government, and to organized bodies, or when used as proper names. For example: Lake Michigan, State of Michigan, or the State, the Province, the Republic, or the National and State Governments, Washtenaw County, Ann Arbor Township, Huron River, Pacific Ocean, North Atlantic, Northern States, Reservoir No. 1, Hoover Dam, Pond No. 1 or Pond A, State Fish Farm No. 1, Pisgah National Forest, American Fisheries Society.

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(a) Abbreviate the following:

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Temperatures—F. (Fahrenheit).

Degrees, whether referring to temperatures, longitude and latitude, or angles, etc.—75°, 75° F., 75° C.

"*Number*," when preceding figures—No. 125; otherwise spell out.

"*United States*," if preceding name of a department or a bureau or a vessel, etc.—U. S. Department of the Interior, U. S. S. *Indiana*.

Months, in body of tables and footnotes to same when followed by day of month—Apr. 5-Sept. 2 (but April-September).

(b) Do not abbreviate the following:

States, cities, etc.

Months, in text or in headings of tables—April 5-September 2.

Measures and weight, except p.p.m.—6 inches, 20 millimeters, 5 ounces, 1.5 acres, etc.

Percentage—12 percent, a percentage of 25.5.

14. **Numerals.** Spell out all *isolated* numbers less than 10, but use figures in a group of enumerations when any one number of that group is 10 or greater. Do not spell out numbers of two or more digits (except round numbers of approximations: estimated at five hundred; a thousand fish), and always use a comma in a number of four or more digits. Treat alike all numbers in a series of connected groups. For example: There were nine trout. There were 9 trout, 120 bass, and 50 pike.

Use figures for all enumerations of quantities and measurements, such as dimension, weight, area, volume, distance, clock time, time, money, percentage, degrees, proportion or ratios, ages, dates, page numbers, decimals, and mixed numbers (spell out common fractions if alone: one-eighth inch). For example: $3.00 per 20 pounds; 5 feet 6 inches; 10 miles; 6 acres; 15 cubic centimeters; 4:30 p.m.; fish died in 1 hour and 20 minutes; 25.5 percent; 75° F.; 1:10,000; trout 2 years 6

months old; 2-year-old trout; June 29, 1936; the 1st of January, 1938; the 20th day of March; 1937-38; 4.5 p.p.m.; 0.25, 1½ pages; page 215.

Write 8 by 12, not 8 x 12 unless multiplication is indicated. Write 50-50, not "fifty-fifty."

Do not use two figures when two numbers appear together, unless the first enumeration exceeds 100: ten 12-room houses; twenty 6-inch trout; 120 6-inch trout.

Spell out figures beginning a sentence, but avoid such use of numerals if possible. Spell out both numbers of two related amounts at the beginning of a sentence in such expressions as "Twenty to twenty-five trout," but write "Two hundred fifty bass and 325 trout were shipped."

Spell out such indefinite expressions as the following: Between two and three hundred fish; there were thirty or forty thousand trout.

In expressing large numbers the word *million* (or a similar larger group term) may be spelled out: 20 million, 2¾ billions.

15. **Use of hyphen.** Many compound words when used as nouns are not hyphenated but require use of the hyphen when used as adjectives. For example note the following sentences: "This species is adapted to *cold water.*" "Trout are *cold-water* fish." Write "fish culture," but "fish-culturist." Check your manuscript carefully for use of hyphen. The words, "subspecies," "upstream" and many other words originally of compound derivation are written without a hyphen.

Write "largemouth" and "smallmouth" as one word when referring to black bass.

III. SUBJECT MATTER

16. **Condense your paper** to the limit and omit all needless verbiage to reduce cost of printing. The manuscript should be simple, direct, clear, concise, accurate, consistent, and complete. *Accuracy* in subject matter, in scientific names, and in bibliography is especially important. Have your associates read and criticize your paper before the final typing. **Papers which are too poorly written will be rejected.** Do not expect your Editorial Board to rewrite your manuscript.

17. **Be definite in references to species.** The scientific name, and wherever needed the *complete* common name, that will identify the species about which the paper is written should be included in the title as well as in the text, unless the number of species is too large. Such names as "bass," "trout," "pike," and "pickerel" apply to any one of several species. Do not write "smallmouth," "brook," "rainbow," etc., when you mean "smallmouth black bass," "brook trout," "rainbow trout," etc.

18. **Things to avoid.** Words that do not appear in the dictionary in the sense employed should be avoided. The *words* "case," "instance," "show," "found," "gave," and "present" are greatly overworked in manuscripts.

Avoid the repeated use of *participles* which, as a rule, weaken sentences. In the following illustration note the improvement when the words in parentheses are used: "The principles underlying (that underlie) the production of beef are essentially the same as those involving (that are involved in) the production of bass."

Avoid *split infinitives.* Please check your manuscript for this exceedingly common error.

Avoid the use of *this* and *these* as substantives. Compare, for example, the following two sentences for effectiveness: "*This* was true in every *case.*" "*The mortality was high* in every *pond.*"

Avoid the use of a long series of nouns and adjectives as modifiers.

19. **Abstract of paper.** Give a condensed summary or brief abstract at the beginning of your paper.

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INDEX TO VOLUME 74

A

Abalone, 79
Absorption, salt, 297-309
Abundance, Atlantic salmon, decline, 191-195
  kiyi, 143-165
Acriflavine, as disinfectant, 33
Adams, William C., 3
Age and growth, bloater, Lake Ontario
  kiyi, 89-194
Age composition, kiyi, Lake Michigan, 92-96
Aguja, 77
Albacore, 72
Albulidae
  Albula vulpes, 77, 267-275
Alewife, Lake Ontario, 234-237
Algae, blue-green, 254-255
  filamentous, 254-255, 340
  in Hawaiian fish ponds, 25-261
Alkalinity, methyl-orange, 224-228
  Tennessee streams, 223-229
Almeja, 77
Ameiuridae
  Ameiurus natalis, 360-369
Ammonia content, ponds, 340-343
Ammonium sulphate, fertilizer, 342-343
Amphora, 254-255, 272
Anchoviella purpurea, 265, 267, 270-275
Anchovy, Hawaiian, 265, 267, 270-275
Anemia, 212-215
  of trout, 81-87
Angling experiment, trout, 63-70
Annelida
  Nereis sp., 268-271
Archaen formation, 225
Arctocorixa, 268-271
Argyreiosus brevoorti, 76
  oerstedii, 76
Ariidae
  Sciadeichthys troschelii, 76
Artificial propagation, Atlantic salmon, 188-208
  efficiency, 199-206
Atarrayas, 78
Atún, 72
Audouinia semi-cinctus, 274
Au Sable River, trout plantings, 37-47

B

Bacalao, 73
Bacterial disease, 22-23, 81
Bacterium salmonicida, 23, 26-34
Bagre, 76
Baker, Clarence M. (In Memoriam), 10
Ball, Robert C., 360-369
Barracuda, 74
  Hawaiian, 267-275
Barrilete, 72
Bass, largemouth, tagging, 360-369
  rock, 75
  smallmouth, pond production, 338-349
Baths, salt, 297-309
Bathymetric distribution, kiyi, 147-155
Batis maritima, 254-255, 265-266
Baya, 75
Belonidae
  Strongylura sp., 77
Benthonic plants, 265
Biotic interaction, fish ponds, 262-280
Bithynia grandimanus, 267-275
Blackfin, Lake Michigan, 144
Blackledge River, population depletion, 166-187
Bloater, Lake Michigan, 144-145
  Lake Ontario, 230-249
Blood salt, 297-309
Bluegill, tagging, 360-369
Bocado de Dios, 76
Bolvinita, 255
Bombing, re smelt mortality, 317
Bonefish, 267-275
Bonito, 72
Branchiostegidae
  Caulolatilus princeps, 76
Bullhead, tagging, 360-369
"Burro", 77
By-Laws and Constitution, 373-376

C

Cabrilla, 75
Calculation, disinfectant quantities, 210-215
Callinectes toxotes, 78
Camarón, 78
Cambrian formation, 225
Carangidae
  Argyreiosus brevoorti, 76
  oerstedii, 76
  Caranx, 72
  sexfasciatus, 267-275
  Trachinotus sp., 77
Carchariidae
  Eulamia, 73
Carp, 22
Cascadilla Creek, angling experiment, 63-70
Cast nets, 78
Catán, 76
Catch, correlation, 207-208
  per unit effort, smelt, 327-331
  trout, 174-182
Catfish, 22
  sea, 76
Catostomidae
  Catostomus catostomus, 234-237
  commersonnii, 234-237
Cazón, 73
Centrarchidae
  Huro salmoides, 360-369
  Lepomis gibbosus, 360-369
  macrochirus, 360-369
  Micropterus dolomieu, 338-349
Centropomidae
  Centropomus, 75
Certificate of incorporation, 372
Chanidae
  Chanos chanos, 74-75, 250-261, 262-263, 267-275
Chapeta, 76
Chattanooga shale formation, 225
Cherna, 76
Chilodon, 24, 219
Chlorides, blood, 297-309
Chlorine, as disinfectant, 27-32
Chloromyxum sp., 24
Chub, Lake Michiagn, 144-145
Chucumite, 75
Chute, Walter H., 4
Cierras, 78
Cisco fishery, Lake Ontario, 230-249
Cladophora, 252, 254-255, 265, 340
Clam, Pismo, 80
Clark, Arthur L., 4
Clemens, W. A., 4
Clupeidae
  Pomolobus pseudoharengus, 234-237
  Sardinops caerulea, 72

Cobb, Kenneth E., 3
Coefficient of condition, 122-127
Committees, membership of, 4-5
Concentrations, disinfectant, 219-221
Concha madre perla, 80
Condition, coefficient of, 122-127
  Lake Ontario bloaters, 238-239
Congener, 252
Conservation, kiyi, 140-141
Constitution and by-laws, 373-376
Control, hatchery diseases, 209-222
Convict Creek, Calif., trout spawning, 281-296
Copepods, 255
Copper sulphate, for fungus control, 34
Corbina, 75
Coregonidae
  Coregonus clupeaformis, 234-237
  Leucichthys alpenae, 144
    artedi, 144, 230-234
    hoyi, 144-145, 230-249
    kiyi, 89-142, 143-165, 230-249
    nigripinnis, 144
    reighardi, 144-145, 158, 230-249
    zenithicus, 144-145
  prosopium cylindraceum quadrilaterale, 234-237
Cornuda, 73
Corophium sp., 268-271
Correlation, commercial and rod catches, 207-208
Coryphaenidae
  Coryphaena hippurus, 77
Coscinodiscus, 254-255
Costia, 24, 219
Cottidae
  Cottus cognatus, 234-237
  Triglopsis thompsonii, 234-237
Cottonseed meal, fertilizer, 342-343
Crab, Hawaiian, 267-275
  Mexican, 78
  mud, 267-275
  red, 267-275
  Samoan, 267-275
  swimming, 273
Crangon crassimanus, 268-271, 273
Crappie, 24
Cretaceous formation, Upper, 225
Cristivomer namaycush, 234-237
Crustacea
  Bithynis grandimanus, 267-275
  Callinectes toxotes, 78
  Corophium sp., 268-271
  Crangon crassimanus, 267-275
  Daphnia, 351
  Euphylax dovii, 78
  Gammarus, 272
  Leander debilis, 255, 267-275
    pacificus, 267-275
  Mexican, 71-80
  Mysis, 155
    relicta, 236-237
  Panopeus pacifica, 267-275
  Panulirus inflatus, 79
    interruptus, 79
  Penaeus californiensis, 78
    stylirostris, 78
    vannamei, 78
  Podophthalmus vigil, 267-275
  Pontoporeia, 155
    hoyi, 236-237
  Portunus sanguinolentus, 267-275
  Scylla serrata, 267-275
  Thalmita integra, 273-275
Cycles, Atlantic salmon runs, 195-199
  food, Hawaiian fishes, 250-261, 262-280
Cyclopsetta panamensis, 76
  querna, 76
Cymbella, 254-255, 272
Cynoscion, 75
  macdonaldi, 73-74
Cyprinidae
  Margariscus margarita, 24
Cytophaga columnaris, 23

D

Daphnia, 351
Davis, H. S., 21-25
Deason, Hilary J., 4, 89-142, 143-165
Death rate and temperature, 355-359
Depletion, trout population, 166-187
Diapterus linneatus, 76
Diatoms, 254-255
Diet composition, trout, 83-85
Disease, bacterial gill, 81
  hatchery, control of, 209-222
  infectious, 21-25
  parasitic, treatment, 219-221
  re smelt mortality, 320
Disinfectant concentrations, 219-221
    calculation of, 210-215
Disinfection of hatcheries, 26-34
Distribution, bathymetric, kiyi, 143-165
Dolomite, Knox, formation, 225
Donaldson, Lauren R., 4
Dorado, 77
Dytiscus, 272
Dymond, John R., 4

E

Earthquake, re smelt mortality, 317
Ecological classification, 266-267
Edema, trout, 302-303
Eel, 22
Effect, physiological, sodium chloride, 297-209
Efficiency, experimental gillnets, 237-238
Effort, catch per unit, 174-182
Eggs, definition and measurement, 19-20
  disinfection of, 31
Eleotridae
  Eliotris fuscus, 267-275
Elopidae
  Elops affinis, 252
    machnata, 250-261, 267-275
Enteromorpha, 252, 254-255, 265
Engraulidae
  Anchoviella purpurea, 265, 267-275
Eocene formation, 225
Epinephalidae
  Epinephalus, 75
  Mycteroperca, 75
  Promicrops itaiara, 75-76
  Sterolepis gigas, 75-76
Eschmeyer, R. W., 3
Excretion, salt, 297-309
Eulamia, 73
Euphylax dovii, 78

F

Feast, C. N., 4
Feeding habits, Hawaiian pondfishes, 250-261
Fertilizers, composition of, 342
Fin clipping, 360-369
Fingerlings, definition and measurement, 19-20
Fish (see under common and scientific name)

Fish culture, standard terms, 19-20
Fish, Frederic F., 209-222
Fishing effort, trout stream, 169-173
Food chains, Hawaiian fishes, 250-261, 262-280
  cycles, Hawaiian fishes, 250-261, 262-280
Foraminifera, 255
Formalin, disinfectant, 219-221
Fry, definition and measurement, 19-20
Fungus, control of, 34
Furunculosis, 22-23

G

Gallo, 77
Gambusia, 351
Gammarus, 272
Garfish, 76
Geological formations, Tennessee streams, 223-229
Geochemical interpretation, water analyses, 223-229
Germo alalunga, 72
Gerridae
  Diapterus linneatus, 76
  Eucinostomus, 76
  Gerres cinerus, 76
Gill disease, bacterial, 81
  disorder, 212-215
Gillnets, experimental, 92, 94, 145-147
    efficiency, 237-238
    Lake Ontario, 234-239
Globigerina, 255
Gobiidae
  Gnatholepis anjerensis, 267-275
  Gobiichthys papuensis, 267-275
Goby, Hawaiian, 267-275
Goose barnacle, 78
Gordon, Seth, 5
Gottschalk, John, 4
Great Lakes, smelt mortality, 310-337
Griffiths, Francis P., 5
Grouper, 75
Growth and age, kiyi, 89-142
  compensation, kiyi, 116-118
  Lake Ontario bloater, 239-243
  rate, change in, 334-336
    marked fish, 367-369
Gyrodactylus, 25, 219

H

Haemulidae
  Pomadys sp., 77
Halibut, California, 76
Haliotis, spp., 79
Halophila ovalis, 265
Halopyhtes, emergent, 265
Hatchery, disease control, 209-222
  disinfection and maintenance, 26-34
Hay, as pond fertilizer, 342-343
Hazzard, A. S., 5
Hemiramphidae
  Hyporamphus sp., 77
Herring, lake, 144, 230-244, 312
Herrington, William C., 4
Hiatt, Robert W., 250-261, 262-280
Hildebrand, Samuel F., 4
Hile, Ralph, 4, 89-142, 143-165
Hogan, Joe, 3
Huachinango, 75
Hubbs, Carl L., 4
Huro salmoides, 360-369
Huron, Lake, smelt mortality, 310-337
Hunter, R. P., 3, 14-15
Huntsman, A. G., 4
Hydrodictyon, 340
Hydrogen-ion concentration, 224-228
Hydrophilus, 271
Hyporamphis sp., 77

I

Ice formation and smelt mortality, 318
Ichthyophthirius, 24, 219
Incorporation, Certificate of, 372
Instructions, preparing manuscripts, 391-394
Istiophoridae
  Istiophorus greyi, 77
  Makaira marlina, 76-77
    mitsukurii, 76-77

J

Jackson, Charles E., 4
Jaibas, 78
Jewfish, 75-76
Jorobado, 76
Jurel, 72

K

Kaku, 268
Katsuwonus pelamis, 72
Kiyi, age and growth, 89-142
  bathymetric distribution, 143-165
  sex ratio, 133-140
Knife River, planted trout, 51
Knox dolomite formation, 225

L

"Lab-lab," 262
Lactobacillus casei, 82
Lake (see under proper name)
Langostina, 79
Leander debilis, 255, 267-275
  pacificus, 267-275
Lebistes, 350-359
Length-frequencies, kiyi, 96-107
  bloater, 239-243
  calculated, kiyi
  weight relationship, 122-127
Leonard, Justin W., 4
Lepisosteidae
  Lepisosteus, 76
Lepomis gibbosus, 360-369
  macrochirus, 360-369
Leucichthys alpenae, 144
  artedi, 144, 230-234
  hoyi, 144-145, 230-249
  Johannae, 144
  kiyi, 89-142, 143-165, 230-249
  nigripinnis, 144
  reighardi, 144-145, 158, 230-249
  zenithicus, 144-145
Lindner, Milton J., 71-80
Lisa, 74
Little, G. Scott, 63-70
Lizard fish, 270
  Hawaiian, 267-275
Lobster, spiny, 79
Locke, S. B., 5
Longjaw, Lake Michigan, 144
Lookdown, 76
Lutianidae, 75
Lymphocystis disease, 24

M

Macabí, 77
Macarela, 22
MacKay, H. H., 3
Mackerel, Pacific, 72
  Spanish, 76
Maintenance of hatcheries, 26-34

Makaira marlina, 76-77
mitsukurii, 76-77
Manure, sheep, as pond fertilizer, 342-343
Manuscripts, instructions for preparing, 391-394
Margariscus margarita, 24
Marked trout, recovery, 172-173
Marking fish, 360-369
Marlin, 76-77
Marphysa sanguinea, 274
Martillo, 73
Mastogloia, 254-255
Maturity, bloater, 239
kiyi, size at, 133
Maxillary tag, 360-369
McCormac, Fred, 4
Measurement, methods for fish culture, 19-20
fish scales, 59-62
Megalopidae
Tarpon atlanticus, 75
Melosira, 254-255
Members, list of, 377-390
Meriamopedia, 254-255
Mero, 75-76
Methyl-prange alkalinity, 224-228
Mexico, commercial fishes, 71-80
Michigan, Lake, kiyi, age and growth, 89-142
kiyi distribution and abundance, 143-165
smelt mortality, 310-337
spawning of kiyi, 159-164
temperature, 151-155
Microbenthos, 262-263
Microcystis, 254-255
Micropterus dolomieu, 338-349
Migration, planted trout, 44-46
re smelt mortality, 319-320
trout, 168-169
Milkfish, 74-75, 250-261, 262-263, 267-275
Minnow, pearl, 24
Mississippian formation, 225
Mojarra, 76
Mollienesia latipinna, 255, 265, 268-275
Mollusca
Haliotis sp., 79
Ostrea chilensis, 79
Pinctada mazatlantica, 80
Planaxis labiosus, 255
Tivela stultorum, 80
West coast of Mexico, 71-80
Moore, Emmeline, 5
Mortality, cutthroat trout, 286-287
planted trout, 52-55
smelt, 310-337
trout, 169
Mottley, C. McC., 4
Mugilidae
Mugil capito, 251
cephalus, 74, 250-261, 262, 264, 267-275
curema, 74
Mullet, 74, 250-261, 262, 264, 267-275
muriate of potash, fertilizer, 342-343
Mycteroperca, 75
Myers, George S., 4
Myxis, 155
relicta, 236-237
Myxosporidia, 23

N

Nainereis laevigata, 274
Natural spawning, efficiency, 200-206
Navicula, 254, 272
Nematistiidae
Nematistius pectoralis, 77
Nematoda, 254-255
Neothunnus macropterus, 72
Nereis sp., 268-271
Nets, experimental, efficiency, 237-238
gill, 92, 94, 145-147
in Lake Ontario, 234-239
Nitrate nitrogen, 346
Nitrite nitrogen, in fish ponds, 343-346
Nitrogen content, variations, 338-349
Nitzchia, 254-255
Nutritional anemia, 81

O

Octomitus, 23
O'Donnell, D. John, 26-34
Oedogonium sp., 252, 340
Officers, list of, 3
Oncorhynchus tschawytscha, 293
Ontanagon River. trout plantings, 37-46
Ontario, Lake, cisco fishery, 230-249
growth of kiyi, 107-108
"O'opuhue," 272
"Oop," 271
"Oopu akupa," 270
Ordovician formation, 225
Organic nitrogen, 346-347
Oscillatoraceae, 265
Oscillatoria, 254-255
Osmeridae
Osmerus mordax, 234-237, 310-337
Ostión, 79
Ostrea chilensis, 79
Otolithidae
Cynoscion, 75
macdonaldi, 73-74
Overcrowding, re smelt mortality, 319
Oxygen consumption, 214-215
Oysters, Mexican, 79
pearl, 80

P

Paloma, 77
Palometa, 77
Pampano, 77
Panopeus pacifica, 267-275
Pantothenic acid requirement, trout, 81-87
"Paoo kaulaloa," 271
Panulirus inflatus, 79
interruptus, 79
Papagallo, 77
Papio, Hawaiian, 267-275
Paralabrax, 75
Paralichthys californicus, 76
Parathunnus mebachi, 72
Pargo, 75
Pell, S. Morris, (In Memoriam), 10
Penaeus californiensis, 78
stylirostris, 78
vannamei, 78
Pennsylvanian formation, 225
Penobscot River, Atlantic salmon, 188-208
Percebes, 78
Perch, yellow, Lake Ontario, 234-237
Percidae
Perca flavescens, 234-237
Stizostedion vitreum glaucum, 234-237
Pescado blanco del mar, 76
Pez espada, 77
Pez gallo, 77
Pez vela, 77
Phillips, Arthur M., Jr., 81-87, 297-309
Physiological change, re smelt mortality, 319
Pike, walleye, 312

Pike-perch, blue, 234-237
Pilchard, 72
Pinctada mazatlantica, 80
Pinnularia, 274
Pintilla, 75
Planaxis labiosus, 255
Plantings, trout, 35-38
Pleistocene formation, 225
Pleuronectidae
Cyclopsetta panamensis, 76
querna, 76
Pleurosigma, 254-255, 272
Pneumatophorus diego, 72
Podophthalmus vigil, 267-275
Poeciliidae
Gambusia, 351
affinis, 255, 267-275
Lebistes, 350-359
Mollienesia latipinna, 255, 265-275
Xiphophorus, 351
Pollution, effect on salmon runs, 189
re smelt mortality, 317
Polychaetes, 267-275
Polydora ciliata, 274
Polysiphonia, 254-255
Pomadasys sp., 77
Pomolobus pseudoharengus, 234-237
Pondfishes, Hawaiian, 250-261, 262-280
Ponds, nitrogen content variations, 338-349
fertilizers, 342
Pontoporeia, 155
hoyi, 236-237
Population depletion, trout, 166-187
dynamics, 351-354
laboratory study, 350-359
Portunus sanguinolentus, 268-275
Potamilla elonga, 274
Pre-Cambrian formation, 225
President, report of, 13-14
Presidents, list of past, 6-7
Pritchard, A. L., 4
Production, bass in ponds, 338-349
Promicrops itaiara, 75-76
Propagation, artificial, Atlantic salmon, 188-208
efficiency, 199-206
Prosopium cylindraceum quadrilaterale, 234-237
Protozoan fish diseases, 22-24
Puffer, Hawaiian, 267-275
Pulvinulina, 255

Q

Quijo, 77

R

Rayner, H. John, 166-187
Recovery of marked trout, 172-173
Reid, Kenneth A., 5
Relationship, length-weight, 122-127
Riboflavin requirement, trout, 81-87
River (see under proper name)
Robalo, 75
Roccal, hatchery disinfectant, 209-222
Rodd, James A., 5, 19-20
Roncador, 77
stearnsi, 77
Rounsefell, George A., 188-208

S

Sábalo, 74-75
Sabalote, 74-75
Sailfin, Hawaiian, 265, 267-275
Sailfish, 77
Salinity, trout blood, 297-309
Salmon, Atlantic, 293-294
abundance decline, 181-195
artificial propagation, 188-208
cycles, 195-199
chinook, oxygen, consumption, 214-215
scales, measuring, 59-62
Salmonidae
Oristivomer namaycush, 234-237
Oncorhunchus tschawytscha, 293
Salmo clarkii henshawi, 281-296
gairdnerii, 63-70, 166-187
salar, 188-208, 293-294
trutta, 35-58, 166-187
Salvelinus fontinalis, 35-58, 81-87, 166-187, 281-296, 297-309
Sarda lineolata, 72
velox, 72
Sardine, California, 72
Sardinops caerulea, 72
Saurida gracilis, 267-275
Scale method, 59-62, 92
Schultz, Leonard P., 4
Sciadeichthys troschelii, 76
Sciaenidae
Roncador stearnsi, 77
Umbrina sinaloe, 77
Scofield, W. L., 3
Scombridae
Pneumatophorus diego, 72
Scomberomorus sierra, 76
Sculpin, deep-water, 234-237
northern, 234-237
Scylla serrata, 267-275
Senescence, re smelt mortality, 319
Seriolidae
Seriola colburni, 72
dorsalis, 72
Serranidae
Paralabrax, 75
Sex ratio, kiyi, 133-140
Lake Ontario bloater, 239
Lebistes, 357
Shale formation, Chattanooga, 225
Shapovalov, Leo, 59-62
Shark, 73
Shetter, David S., 35-58
Shoemaker, Carl D., 3, 5
Shoemaker, Hurst H., 350-359
Shoup, C. S., 223-229
Shrimp, Hawaiian, 267-275
Mexican, 78
snapping, 267-275
Sibley, E. L. (In Memoriam), 10
Sierra, 76
Silurian formation, 225
Simon, James R., 3
Skipjack, 72
Sleeper, Hawaiian, 267-275
Smelt, catch per unit effort, 327-331
commercial production, 326-333
Lake Ontario, 234-237
mortality, 310-337
species interrelationship, 312
Smith, M. W., 5
Smith, Osgood R., 281-296
Snapper, 75
Sodium chloride, effect on trout, 297-309
thiosulphate, as disinfectant, 28
Spawning, kiyi, 159-164
loss of weight at, 127-133
natural, efficiency, 200-206
results, 281-296
season, kiyi, 143-165
Spet, 268

Sphyraenidae
Sphyraena argentea, 74
barracuda, 267-275
ensis, 74
Spirogyra, 252, 254-255, 340
Spiroloculina, 255
Sterolepis gigas, 75-76
Stizostedion vitreum glaucum, 234-237
Stocking trout, spring and fall, 35-58
Stone, Udell Bennett, 230-249
Storms, smelt mortality cause, 317
Strongylura sp., 77
Sturgeon River, trout plantings, 37-46
Sucker, common, Lake Ontario, 234-237
fine-scaled, Lake Ontario, 234-237
Sunfishes, 24
pumpkinseed, tagging, 360-369
Superphosphate, 342-343
Supersonic vitrations, re smelt mortality, 317
Surber, Eugene W., 338-349
Surirella, 254-255
Survival, cutthroat trout, 286-287
Survival, hatchery trout, 40-42
re smelt mortality, 319
Swordfish, 76-77
Synodontidae
Saurida gracilis, 267-275

T

Tagging fish, 360-369
Tarpon atlanticus, 75
Temperature, Lake Michigan, 151-155
relation to death rate, 355-357
re smelt mortality, 318
Tennessee streams, geological formations, 223-229
water analyses, 223-229
Ten-pounder, 267-275
Hawaiian, 250-261
Tetraodontidae
Tetrodon hispidis, 267-275
Thalmita integra, 273-275
Third Sister Lake, fish tagigng, 360-369
Thompson, W. T., (In Memoriam), 10
Thorpe, Lyle M., 166-187
Thrips, 272
Thunnidae
Germo alalunga, 72
Katsuwonus pelamis, 72
Neothunnus macropterus, 72
Parathunnus mebacki, 72
Sarda lineolata, 72
velox, 72
Thunnus thynnus, 72
Thysanoptera, 272
Tiburón, 73
Tivela stultorum, 80
Totoaba, 73-74
Townsend, Charles H., (In Memoriam), 10
Trachinotus sp., 77
Treasurer, report of, 14-15
Trichodina, 24
Triglopsis thompsonii, 234-237
Trout, brook, depletion, 166-187
effect of sodium chloride, 297-309
plantings, 35-58
riboflavin and pantothenic acid, 81-87
results, spawning, 281-296
brown, depletion, 166-187
plantings, 35-58
cutthroat, results, spawning, 281-296
hatcheries, disinfection, 26-34
maintenance, 26-34
lake, 312, 234-237
planted, migration of, 44-46
population depletion, 166-187
rainbow, angling experiment, 63-70
depletion, 166-187
plantings, 35-58
scales, measuring, 59-62
Trypanosoma, 23
Tucker, William J., 4
Tuna, big-eye, 72
bluefin, 72
yellowfin, 72
Tunison, A. V., 81-87

U

"Ulae," 270
"Ulua," 272
Ulva, 265
Umbrina sinaloe, 77
Upper Cretaceous formation, 225

V

Valisneria, 351
Van Oosten, John, 3, 13-14, 310-337
Vaucheria, 252, 254-255, 265
Vitamin content, diets, 83-85
studies, trout, 81-87

W

Wales, Joseph H., (In Memoriam), 10
Water analyses, geochemical interpretation, 223-229
Webster, Dwight A., 63-70, 166-187
Weight, loss at spawning, 127-133
growth in, kiyi, 113-116
Weirs, 78
Westerman, F. A., 4
Whitefish, 312
Lake Ontario, 234-237
ocean, 76
round, Lake Ontario, 234-237
Wickliff, E. L., 4
Wilsno, C. H., (In Memoriam), 10
Wire, Frank B., 4
Worms, parasitic, 35

X

Xanthopterin, 81
Xiphiidae
Xiphias gladius, 76-77
Xiphophorus, 351

Y

Yearlings, definition and measurement, 19-20
Yellowtail, 72

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